(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 330 027 A2

(12) # EUROPEAN PATENT APPLICATION

(43) Date of publication:
23.07.2003 Bulletin 2003/30

(51) Int Cl.7: H03H 9/64

(21) Application number: 03290156.3

(22) Date of filing: 22.01.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT SE SI SK TR
Designated Extension States:
AL LT LV MK RO

(30) Priority: 22.01.2002 JP 2002012799
11.11.2002 JP 2002327478

(71) Applicant: Murata Manufacturing Co., Ltd.
Nagaokakyo-shi Kyoto-fu 617-8555 (JP)

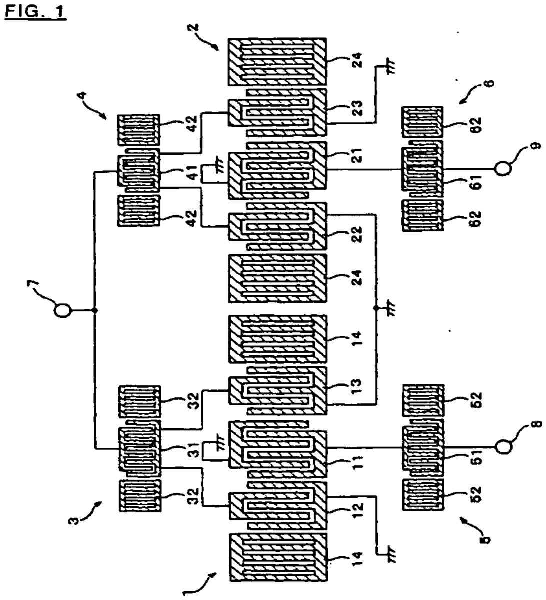
(72) Inventors:
- Shibata, O., (A170) I.P.D., Murata Man., Co, Ltd.
Nagaokakyo-shi, Kyoto-fu 617-8555 (JP)
- Takamine, Y., (A170) I.P.D., Murata Man., Co, Ltd.
Nagaokakyo-shi, Kyoto-fu 617-8555 (JP)

(74) Representative: Thévenet, Jean-Bruno et al
Cabinet Beau de Loménie
158, rue de l'Université
75340 Paris Cédex 07 (FR)

(54) **Surface acoustic wave device and communication device comprising it**

(57) A surface-acoustic-wave device having an unbalanced-to-balanced conversion function, which is capable of improving balanced characteristics, is provided. The surface-acoustic-wave device includes a first resonator filter (1) and a second resonator filter (2), each having a plurality of interdigital transducers (11-13/21-23) formed along the propagation direction of a surface-acoustic wave. The surface-acoustic-wave device has an unbalanced-to-balanced conversion function as a result of the phase of the second resonator filter (2) being reversed by 180° with respect to that of the first resonator filter (1). The surface-acoustic-wave device further includes a first resonator (3) connected in series to an unbalanced signal terminal side of the first resonator filter (1), and a second resonator (4) connected in series to an unbalanced signal terminal side of the second resonator filter (2). The first resonator (3) and the second resonator (4) are formed with different design parameters.

FIG. 1



Printed by Jouve, 75001 PARIS (FR)

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates to a surface-acoustic-wave device used for delay lines, filters, etc., and to a communications device having the surface-acoustic-wave device.

2. Description of the Related Art

[0002] Since electronic devices have become smaller in size and lighter in weight in recent years, there has been an increasing demand for electronic devices with multiple functions. With such a background, there has also been an increasing demand for surface-acoustic-wave filters (hereinafter referred to as "SAW filters") serving as surface-acoustic-wave devices used in communications devices, such as cellular phones, to have an unbalanced-to-balanced conversion function so that the SAW filters can be directly connected to an IC which operates by using a balanced input, and active research has been intensively carried out in this area.

[0003] In particular, in a SAW filter formed of a resonator filter, having an unbalanced-to-balanced conversion function, the amplitude difference and the phase difference on the balanced side are important characteristics (hereinafter referred to as "balanced characteristics"), and it is required that the amplitude difference be 0 dB and the phase difference be 180° on the balanced side. However, in practice, since the tendencies of the balanced characteristics also differ according to the structure of the SAW filter, it is not possible to completely achieve an amplitude difference of 0 dB and to achieve a phase difference of 180°, and improvement of the balanced characteristics with respect to the structure of the SAW filter has become an objective.

[0004] For the surface-acoustic-wave device having an unbalanced-to-balanced conversion function, there are various structures according to the type and purpose of an IC. For example, for the surface-acoustic-wave device in which the matching impedance on the balanced side is approximately four times as large as the matching impedance on the unbalanced side, the structure such as that shown in Fig. 12 is widely used.

[0005] A surface-acoustic-wave device shown in Fig. 12 is configured in such a manner that a resonator filter 100 and a resonator filter 110, which is 180° out of phase with the resonator filter 100, are provided on a piezoelectric substrate (not shown).

[0006] The resonator filter 100 is provided with a comb-shaped electrode part (an interdigital transducer, hereinafter abbreviated as an "IDT") 101, and IDTs 102 and 103 are arranged on the right and left sides (the right and left direction along the propagation direction of the surface-acoustic wave) of the IDT 101. Furthermore, in the resonator filter 100, reflectors 104 and 105 are arranged in such a manner so as to sandwich the IDTs 101, 102, and 103 from the right and left (the right and left direction along the propagation direction of the surface-acoustic wave) respectively.

[0007] The IDT is formed from a metal thin-film of aluminum, etc., and functions as a surface-acoustic-wave conversion section which converts an input electrical signal (AC) into surface-acoustic waves (SAW energy) so that the surface-acoustic waves propagate on the piezoelectric substrate, and which converts the propagated surface-acoustic waves into electrical signals and outputs them. The reflector is used to reflect the propagated surface-acoustic waves back in the direction they came from in order to improve the conversion efficiency.

[0008] In such an IDT, it is possible to set signal conversion characteristics and a passband by setting the length and the width of each comb-shaped electrode finger, the spacing between adjacent comb-shaped electrode fingers, and the finger overlap indicating the opposing length in an interdigitated state between mutual comb-shaped electrode fingers. In the reflector, reflection characteristics can be set by adjusting the width of each reflector electrode finger and the spacing between fingers.

[0009] A resonator filter 110 is provided with an IDT 111 in which the hot (signal side) and the ground side of the electrode finger are reversed with respect to the IDT 101 in the resonator filter 100 so that the phase differs by 180° with respect to the resonator filter 100. IDTs 112 and 113 are provided on the right and left (the right and left direction along the propagation direction of the surface-acoustic wave) of the IDT 111. Furthermore, in the resonator filter 110, reflectors 114 and 115 for reflecting surface-acoustic waves in order to improve the conversion efficiency are arranged in such a manner so as to sandwich the IDTs 111, 112, and 113 from the right and left respectively.

[0010] More specifically, there are provided an unbalanced signal terminal 170 to which the IDTs 102 and 103 in the resonator filter 100 and the IDTs 112 and 113 in the resonator filter 110 are connected in parallel, and balanced signal terminals 180 and 190 which are connected in series to the IDTs 101 and 111, respectively. That is, one side of each of the resonator filters 100 and 110 which are 180° out of phase with each other is connected, and a surface-acoustic-wave device having an unbalanced-to-balanced conversion function is configured in such a manner that the connected unbalanced signal terminal 170 is formed as an unbalanced type and the balanced signal terminals 180 and 190 which

are not connected are formed as balanced types. Meanwhile, for this surface-acoustic-wave device, high attenuation and sharpness of attenuation outside the passband are required.

[0011] Therefore, as shown in Fig. 13, in each of the terminals 170, 180, and 190 of the surface-acoustic-wave device shown in Fig. 12, by arranging trapping resonators 130, 140, and 150 having resonators 131, 141, and 151 in series, respectively, high attenuation and sharpness of attenuation can be obtained outside the passband.

[0012] However, the above-described structure contains factors that deteriorate balanced characteristics. For example, since the hot and the ground of the electrode finger in the central IDT 111 of the resonator filter 110 are reversed with respect to those of the IDT 101 in the resonator filter 100 so that the phase differs by 180° with respect to the resonator filter 100, the number of the hot and the ground of the resonator filter 100 and that of the resonator filter 110 differ, and the ground and the hot are aligned in the IDT-IDT interface, causing an unwanted electric-field to be generated. As one of the countermeasures in the improvement of these balanced characteristics, there is a method of grounding the hot electrode finger, but still a problem remains in the balanced characteristics.

[0013] For the surface-acoustic-wave device shown in Fig. 12, an ideal state is that only the phase difference is 180° between the resonator filter 100 and the resonator filter 110 in the vicinity of the passband. However, after all, for the reasons described above, in practice, the impedance, etc., also differs. As a result, the balanced characteristics deviate from the ideal amplitude difference of 0 dB and the ideal phase difference of 180°. Such an inconvenience is a problem which is inherently possessed by a surface-acoustic-wave device having an unbalanced-to-balanced conversion function, formed of 2-system filter sections which are 180° out of phase with each other. Furthermore, there is no effective improvement method in a case where the balanced characteristics reach a problem level from a practical point of view.

SUMMARY OF THE INVENTION

[0014] The present invention has been made in view of the above-described conventional problems. An object of the present invention is to provide a surface-acoustic-wave device having an unbalanced-to-balanced conversion function, in which balanced characteristics are further improved.

[0015] To achieve the above-mentioned object, the present invention provides a surface-acoustic-wave device comprising: a first surface-acoustic-wave element having a plurality of interdigital transducers formed along the propagation direction of a surface-acoustic wave; and a second surface-acoustic-wave element having a plurality of interdigital transducers formed along the propagation direction of a surface-acoustic wave, the surface-acoustic-wave device having an unbalanced-to-balanced conversion function as a result of the phase of the second surface-acoustic-wave element being reversed by 180° with respect to the first surface-acoustic-wave element, wherein there are provided a first resonator which is connected in series to the unbalanced side of the first surface-acoustic-wave element, and a second resonator which is connected in series to the unbalanced side of the second surface-acoustic-wave element, and the first resonator and the second resonator are formed with different design parameters. The first resonator and the second resonator are preferably surface-acoustic-wave resonators formed of at least one interdigital transducer and reflectors arranged in such a manner so as to sandwich the interdigital transducer.

[0016] According to the above-described arrangement, the first resonator and the second resonator can be designed in accordance with the characteristics of the first surface-acoustic-wave element and the second surface-acoustic-wave element, respectively, and thus balanced characteristics of the surface-acoustic-wave device in unbalanced-to-balanced conversion can be improved by adjusting their design parameters.

[0017] In the surface-acoustic-wave device of the present invention, in addition to the above-described arrangement, the design parameters may be the number of electrode fingers of the reflectors and/or the interdigital transducers in the first resonator and the second resonator.

[0018] According to the above-described arrangement, balanced characteristics of the output on the balanced side can be improved by adjusting the number of electrode fingers in each resonator.

[0019] In the surface-acoustic-wave device of the present invention, in addition to the above-described arrangement, the design parameters may be finger overlaps in the first resonator and the second resonator.

[0020] According to the above-described arrangement, balanced characteristics of the output on the balanced side can be improved by adjusting the finger overlap in each resonator.

[0021] In the surface-acoustic-wave device of the present invention, in addition to the above-described arrangement, the design parameters may be duty ratios in the first resonator and the second resonator. Furthermore, when the duty ratio of reflectors and/or an interdigital transducer in the first resonator is denoted by x and the duty ratio of reflectors and/or an interdigital transducer in the second resonator is denoted by y, the relation $0 < |x - y| \leq 0.05$ is preferably satisfied.

[0022] According to the above-described arrangement, balanced characteristics of the output on the balanced side can be improved by adjusting the duty ratio in each resonator.

[0023] According to the above-described arrangement, balanced characteristics of the output on the balanced side can be improved by adjusting the duty ratio of the first resonator compared to that of the second resonator.

[0024] In the surface-acoustic-wave device of the present invention, in addition to the above-described arrangement, the design parameters may be the distances between the centers of the outermost electrode fingers of the reflectors and the interdigital transducer in the first resonator and the second resonator. Furthermore, when the wavelength determined by the structure of the interdigital transducer of the surface-acoustic-wave element is denoted as λ, and the distance between the centers of the outermost electrode fingers of the reflectors and the interdigital transducer in the first resonator is denoted as $X\lambda$ and the distance between the centers of the outermost electrode fingers of the reflectors and the interdigital transducer in the second resonator is denoted $Y\lambda$, the relation $(0 + 0.5n)\lambda < |X - Y|\lambda \leq (0.18 + 0.5n)\lambda$, where $n = 0, 1, 2...$, is preferably satisfied.

[0025] According to the above-described arrangement, since the distances between the centers of the outermost electrode fingers of the first resonator and the second resonator differ, the amplitude and phase characteristics of the first resonator and the second resonator differ, and the deviation of the degree of balance at higher frequencies of the passband in the first surface-acoustic-wave element and the second surface-acoustic-wave element can be corrected. Therefore, it is possible to obtain a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband.

[0026] In the surface-acoustic-wave device of the present invention, in addition to the above-described arrangement, the design parameters may be the pitch ratios of the reflectors and the interdigital transducer in the first resonator and the second resonator. Furthermore, when the pitch ratios of the reflectors and the interdigital transducer (pitch of the interdigital transducer/pitch of the reflectors) in the first resonator and the second resonator are denoted as a and b, respectively, the relation of $0.984 \leq a/b < 1$ is preferably satisfied.

[0027] According to the above-described arrangement, since the pitch ratio of the interdigital transducer and the reflector differ in the first resonator and the second resonator, the amplitude and phase characteristics of the first resonator and the second resonator differ, and the deviation of the degree of balance at higher frequencies of the passband in the first surface-acoustic-wave element and the second surface-acoustic-wave element can be corrected. Therefore, it is possible to obtain a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband.

[0028] The surface-acoustic-wave device may be housed in a package by a face-down technique.

[0029] The communications device of the present invention comprises one of the above-described surface-acoustic-wave devices.

[0030] Further features and advantages of the present invention will become clear from the following description of preferred embodiments thereof, given by way of example, illustrated by the accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0031]

Fig. 1 is a schematic diagram of a surface-acoustic-wave device according to a first embodiment of the present invention;

Fig. 2 is a graph showing the degree of amplitude balance when the number of electrode fingers in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 3 is a graph showing the degree of phase balance when the number of electrode fingers in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 4 is a graph showing the degree of amplitude balance in a simulation in which the number of electrode fingers in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 5 is a graph showing the degree of phase balance in a simulation in which the number of electrode fingers in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 6 is a graph showing the rate of change in amplitude balance when the duty ratio in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 7 is a graph showing the rate of change in phase balance when the duty ratio in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 8 is a schematic diagram of a surface-acoustic-wave device according to a second embodiment of the present invention;

Fig. 9 is a graph showing the degree of amplitude balance in a simulation in which the finger overlap in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 10 is a graph showing the degree of phase balance in a simulation in which the finger overlap in a resonator of a trapping resonator of the surface-acoustic-wave device is changed;

Fig. 11 is a block diagram of the basic components of a communications device using the surface-acoustic-wave device;

Fig. 12 is a schematic diagram of a conventional surface-acoustic-wave device;

Fig. 13 is a schematic diagram of another conventional surface-acoustic-wave device;
Fig. 14 is a schematic diagram of a surface-acoustic-wave device according to a third embodiment of the present invention;
Fig. 15 is a sectional view of the basic elements of the surface-acoustic-wave device according to the embodiment, which is housed in a package;
Fig. 16 is a graph showing SAW frequency - insertion loss characteristics of the surface-acoustic-wave device according to the third embodiment of the present invention and a surface-acoustic-wave device of comparative example 1;
Fig. 17 is a graph showing frequency - common-mode attenuation characteristics in the surface-acoustic-wave device according to the third embodiment of the present invention and the surface-acoustic-wave device of comparative example 1;
Fig. 18 is a schematic diagram of the surface-acoustic-wave device of comparative example 1;
Fig. 19 is a graph in which the range in which the effects of the surface-acoustic-wave device according to the third embodiment of the present invention are obtained is checked;
Fig. 20 is a sectional view illustrating a manufacturing process for the surface-acoustic-wave device of the above-described embodiments;
Fig. 21 is a sectional view illustrating another manufacturing process for the surface-acoustic-wave device of the above-described embodiments;
Fig. 22 is a schematic diagram of a surface-acoustic-wave device according to a fourth embodiment of the present invention;
Fig. 23 is a graph showing SAW frequency - insertion loss characteristics in the surface-acoustic-wave device according to the fourth embodiment of the present invention and the surface-acoustic-wave device of comparative example 1;
Fig. 24 is a graph showing frequency - common-mode attenuation characteristics in the surface-acoustic-wave device according to the fourth embodiment of the present invention and the surface-acoustic-wave device of comparative example 1;
Fig. 25 is a graph in which the range in which the advantages of the surface-acoustic-wave device according to the fourth embodiment of the present invention are obtained is checked;
Fig. 26 is a schematic diagram of a surface-acoustic-wave device according to a fifth embodiment of the present invention;
Fig. 27 is a graph showing SAW frequency - insertion loss characteristics in the surface-acoustic-wave device according to the fifth embodiment of the present invention and the surface-acoustic-wave device of comparative example 1;
Fig. 28 is a graph showing frequency - common-mode attenuation characteristics in the surface-acoustic-wave device according to the fifth embodiment of the present invention and the surface-acoustic-wave device of comparative example 1; and
Fig. 29 is a graph in which the range in which the advantages of the surface-acoustic-wave device according to the fifth embodiment of the present invention are obtained is checked.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[First Embodiment]

[0032] A first embodiment of the present invention will now be described below with reference to Figs. 1 to 7. As shown in Fig. 1, a surface-acoustic-wave device (SAW device) having an unbalanced-to-balanced conversion function according to this embodiment is configured to include resonator filters (surface-acoustic-wave element, SAW filter) 1 and 2. The resonator filters 1 and 2 have approximately identical passbands. The resonator filters 1 and 2 are provided on a piezoelectric substrate (not shown). The piezoelectric substrate is formed from lithium tantalate, lithium niobate, etc.

[0033] In the resonator filter 1, IDTs 12 and 13 are arranged on the right and left (the right and left direction along the propagation direction of the surface-acoustic wave) of an IDT 11 which is located at the center. Reflectors 14 and 14 are arranged in such a manner so as to sandwich the IDTs 11, 12, and 13 from the right and left (the right and left direction along the propagation direction of the surface-acoustic wave), respectively.

[0034] In the resonator filter 2, IDTs 22 and 23 are arranged on the right and left (the right and left direction along the propagation direction of the surface-acoustic wave) of an IDT 21 which is located at the center. Reflectors 24 and 24 are arranged in such a manner so as to sandwich the IDTs 21, 22, and 23 from the right and left (the right and left direction along the propagation direction of the surface-acoustic wave), respectively.

[0035] It is designed that the IDT 11 and the IDT 21 are arranged in such a manner that the hot (signal side) and the

ground side of their electrode fingers are reversed, with the result that the resonator filter 1 and the resonator filter 2 are 180° out of phase with each other.

[0036] The resonator filters 1 and 2 are connected in parallel to an unbalanced signal terminal 7. The resonator filter 1 is connected in series to a balanced signal terminal 8, and the resonator filter 2 is connected in series to a balanced signal terminal 9.

[0037] In order to improve attenuation outside the passband, trapping resonators 3 and 5 are connected in series to the resonator filter 1, and trapping resonators 4 and 6 are connected in series to the resonator filter 2. Furthermore, the trapping resonators 3 and 4 are connected to the unbalanced signal terminal 7. The trapping resonators 5 and 6 are connected to the balanced signal terminals 8 and 9, respectively. As described above, since the trapping resonator on the unbalanced signal terminal 7 side is divided into the trapping resonators 3 and 4, balanced characteristics can be adjusted more satisfactorily.

[0038] The trapping resonators 3, 4, 5, and 6 include resonators 31, 41, 51, and 61, respectively, and are configured in such a manner that they are sandwiched by reflectors 32, 42, 52, and 62, respectively, along the propagation direction of the surface-acoustic wave.

[0039] More specifically, the IDTs 12 and 13 of the resonator filter 1 are connected to the resonator 31 of the trapping resonator 3. The IDT 11 of the resonator filter 1 is connected to a resonator 51 of the trapping resonator 5. The IDTs 22 and 23 of the resonator filter 2 are connected to the resonator 41 of the trapping resonator 4. The IDT 21 of the resonator filter 2 is connected to the resonator 61 of the trapping resonator 6.

[0040] With the above-described arrangement, the surface-acoustic-wave device has an unbalanced-to-balanced conversion function in which the impedance of each of the balanced signal terminals 8 and 9 is approximately four times as large as the impedance of the unbalanced signal terminal 7.

[0041] In this embodiment, a description will now be given of a case in which the unbalanced signal terminal 7 side is designed to have an impedance of 50Ω and the balanced signal terminals 8 and 9 sides are designed to have an impedance of 200Ω. In order to study how balanced characteristics vary with the number of electrode fingers in the trapping resonator, a description will now be given by using a specific example. The design parameters in the surface-acoustic-wave device are shown in Table 1. The numbers of the electrode fingers in the trapping resonators 3 and 4 are denoted as N_1 and N_2, respectively, and it is assumed that $N_1 \neq N_2$.

TABLE 1

	Filter 1	Filter 2	Filter 3	Filter 4	Filter 5	Filter 6
Number of electrode fingers in the reflectors	100	100	30	30	30	30
Number of electrode fingers in the center IDTs	31	31	N_1	N_2	161	161
Number of electrode fingers in the outer IDTs	25	25	-	-	-	-
Finger overlap (μm)	110	110	85	85	50	50
Center frequency (MHz)	1960	1960	1997	1997	2060	2060

[0042] In the surface-acoustic-wave device of the design shown in Table 1, as shown in Table 2, the balanced characteristics of the surface-acoustic-wave device were studied by making changes based on combinations (1) to (3) of the number of electrode fingers N_1 in the trapping resonator 3 and the number of electrode fingers N_2 in the trapping resonator 4. Furthermore, the ratio of the numbers of electrode fingers in the trapping resonators 3 and 4 is also shown.

TABLE 2

	N_1	N_2	N_2/N_1
(1)	345	297	0.86
(2)	337	305	0.91
(3)	329	313	0.95

[0043] Fig. 2 shows a graph of the degree of amplitude balance of the surface-acoustic-wave device in the combinations (1) to (3). As can be seen from this graph, if N_2/N_1 is increased, the extremal value decreases, and the characteristics at higher frequencies shift toward lower frequencies. The comparison of the extremal values in (1) and (3)

shows that the degree of the amplitude balance is changed from 0.65 dB to 0.85 dB.

[0044] Fig. 3 shows a graph of the degree of the phase balance of the surface-acoustic-wave device in the combinations (1) to (3). As can be seen from this graph, if N_2/N_1 is increased, the degree of the phase balance shifts upwards as a whole (in such a manner that the degree of the phase balance increases). In particular, the amount of changes in the higher frequencies is great, and the degree of the phase balance is changed from 170° to 172.5° in the comparison between (1) and (3).

[0045] It can be seen that, as a result of changing the number of electrode fingers of the trapping resonator connected to the unbalanced signal terminal side in the manner described above, the balanced characteristic are changed. That is, although the balanced characteristics differ depending on the design of the resonator filter, the balanced characteristics can be adjusted by changing the number of electrode fingers of the resonator in the trapping resonator connected to the unbalanced signal terminal side. In the case of this embodiment, as N_2/N_1 is increased, the degree of the phase balance shifts upwards as a whole, and when the amount of change of the minimum value is compared with the maximum value in the passband, the amount of change of the minimum value is greater.

[0046] Figs. 4 and 5 show changes in balanced characteristics when the number of electrode fingers in a resonator in a trapping resonator connected to the unbalanced signal terminal side is changed in a simplified simulation. It can be seen from the results that, for the degree of amplitude balance and the degree of phase balance, the amount of change at higher frequencies is great. This fact matches the tendencies of the actually measured values, and shows that the control of parameters is possible by simulation. The above-described simulation may be performed on the basis of, for example, an equivalent circuit method. Examples of the equivalent circuit method include an equivalent circuit model, a mode coupling theory, etc.

[0047] The changes of the balanced characteristics when the duty ratio of the trapping resonator 3 in the above-described surface-acoustic-wave device was set at 0.42, 0.62, and 0.82 are shown in Figs. 6 and 7. Fig. 6 shows the degree of amplitude balance, and Fig. 7 shows the degree of phase balance. The duty ratio of the trapping resonator 4 is set at 0.62. N_1 is set at 337, and N_2 is set at 305. The other design parameters are identical to those shown in Table 1.

[0048] It can be seen from Figs. 6 and 7 that, by changing the duty ratio of the trapping resonator connected to the unbalanced signal terminal side, the balanced characteristics change. That is, although the balanced characteristics differ depending on the design of the resonator filter, the balanced characteristics can be adjusted at higher frequencies of the passband by changing the duty ratio in the resonator in the trapping resonator connected to the unbalanced signal terminal side. It can be seen from, in particular, Fig. 7 that the phase balance can be adjusted.

[0049] In the foregoing, although the resonator filter is formed of three IDTs, regardless of the design of this embodiment, another configuration in which the resonator filter is formed of a plurality of IDTs, which is not limited to, for example, three, may also be used.

[Second Embodiment]

[0050] Another embodiment of the present invention will now be described with reference to Figs. 8 to 10. For the sake of simplicity of description, components having the same function as that of the components shown in the first embodiment are designated with the same reference numerals, and accordingly, descriptions thereof are omitted here.

[0051] In this second embodiment, in the design which is substantially identical to that of the surface-acoustic-wave device of the first embodiment, the trapping resonator 3 comprising a resonator 31 connected to the unbalanced signal terminal 7 side and the reflectors 32 and 32 which sandwich the resonator 31 is changed to a trapping resonator 3a comprising a resonator 31a and reflectors 32a and 32a which sandwich the resonator 31a. The finger overlap of the resonator 31 differs from that of the resonator 31a. In connection with the above, in order to study how the balanced characteristics vary with the finger overlap in the resonators 3a and 4, a description will now be given by using a specific example. The design parameters in the surface-acoustic-wave device in this example are shown in Table 3. The finger overlaps in the trapping resonators 3a and 4 are denoted as A_1 and A_2, respectively.

TABLE 3

	Trap 3a	Trap 4
Number of electrode fingers in the reflectors	30	30
Number of electrode fingers in the center IDTs	321	321
Finger overlap (μm)	A_1	A_2
Center frequency (MHz)	1997	1997

[0052] Fig. 9 shows changes in balanced characteristics with regard to the degree of amplitude balance of the sur-

face-acoustic-wave device when the finger overlap of a resonator in a trapping resonator connected to the unbalanced signal terminal side is changed in a simplified simulation. Fig. 10 shows changes in balanced characteristics with regard to the degree of phase balance of the surface-acoustic-wave device when the finger overlap of a resonator in a trapping resonator connected to the unbalanced signal terminal side is changed in a simplified simulation. Here, the changes (characteristics) of the balanced characteristics when A_2/A_1 is set at 1.0, 0.79, and 0.62 are shown. It can be seen from Figs. 9 and 10 that the balanced characteristics can be adjusted at higher frequencies within the passband by changing the finger overlap of the resonator in the trapping resonator connected to the unbalanced signal terminal side in a manner similar to that in which the number of electrode fingers is changed.

[0053] In the manner described above, it is possible to adjust the balanced characteristics by making the design parameters of the trapping resonators connected to the unbalanced signal terminal side different from each other.

[0054] Furthermore, not only the number of electrode fingers, the duty ratio, and the finger overlap, but also the pitch between resonators, the width of the electrode fingers, or a method of weighting the electrode fingers may also be used to make the adjustment.

[Third Embodiment]

[0055] A third embodiment of the present invention will now be described with reference to Figs. 14 to 21.

[0056] A surface-acoustic-wave device (SAW device) having an unbalanced-to-balanced conversion function according to this embodiment includes, as shown in Fig. 14, longitudinally coupled resonator-type SAW filters (surface-acoustic-wave elements) 501 and 502, formed from A1 electrodes, provided on a piezoelectric substrate (not shown) formed from 40 ± 5° Y-cut X-propagation $LiTaO_3$. The surface-acoustic-wave device has a balanced-to-unbalanced conversion function in which the impedance of the unbalanced signal terminal is 50Ω and the impedance of the balanced signal terminal is 150Ω. Surface-acoustic-wave resonators (resonators) 503 and 504 are connected in series between an unbalanced signal terminal 515 and the longitudinally coupled resonator-type SAW filter 501 and between the unbalanced signal terminal 515 and the longitudinally coupled resonator-type SAW filter 502, respectively.

[0057] In the longitudinally coupled resonator-type SAW filter 501, IDTs 505 and 507 are formed in such a manner so as to sandwich an IDT 506, and reflectors 508 and 509 are formed on both sides thereof. As shown in Fig. 14, the pitch of several electrode fingers between the IDT 505 and the IDT 506 and between the IDT 506 and the IDT 507 is smaller than the pitch of the electrode fingers of the other portions of the IDT (narrow pitch electrode-finger parts 518 and 519).

[0058] The longitudinally coupled resonator-type SAW filter 502 is configured in such a manner that IDTs 510 and 512 are formed in such a manner so as to sandwich the IDT 511, and reflectors 513 and 514 are formed on both sides thereof. Similarly to the longitudinally coupled resonator-type SAW filter 501, narrow pitch electrode-finger parts 520 and 521 are provided between the IDT 510 and the IDT 511 and between the IDT 511 and the IDT 512. Furthermore, the orientation of the IDTs 510 and 512 of the longitudinally coupled resonator-type SAW filter 502 is reversed to the direction of the finger overlap with respect to the IDT 505 and the IDT 507 of the longitudinally coupled resonator-type SAW filter 501. As a result, the phase of the output signal with respect to the input signal in the longitudinally coupled resonator-type SAW filters 502 is reversed by approximately 180° with respect to the longitudinally coupled resonator-type SAW filter 501.

[0059] In this embodiment, the IDTs 506 and 511 of the longitudinally coupled resonator-type SAW filters 501 and 502 are connected to the balanced signal terminals 516 and 517, respectively. Furthermore, the IDTs 505 and 507 of the longitudinally coupled resonator-type SAW filter 501 are connected to the unbalanced signal terminal 515 via the surface-acoustic-wave resonator 503, and the IDTs 510 and 512 of the longitudinally coupled resonator-type SAW filter 502 are connected to the unbalanced signal terminal 515 via the surface-acoustic-wave resonator 504.

[0060] The surface-acoustic-wave resonators 503 and 504 are configured identically, and reflectors 522 and 525, and reflectors 524 and 527 are formed so as to sandwich the IDTs 523 and 526, respectively.

[0061] Next, the sectional view of a surface-acoustic-wave device housed in a package in this embodiment is shown in Fig. 15. The surface-acoustic-wave device is manufactured by a flip-chip technique of making conduction between the package and a piezoelectric substrate 205 having a surface-acoustic-wave filter formed thereon by bump bonding using bumps 206. (This technique may also be used for manufacturing devices according to the other embodiments of the invention).

[0062] The package is formed in a two-layer structure, and comprises a bottom plate part 201, side-wall parts 202, a die-attach part 203, and a cap 204. This bottom-plate part 201 is shaped, for example, in a rectangular form, and the side-wall parts 202 are arranged in a standing manner from the four peripheral portions of this bottom-plate part 201 correspondingly. The cap 204 covers and seals the opening formed by the side-wall parts 202. On the top surface (inner surface) of this bottom plate part 201, the die-attach part 203 for making conduction with the piezoelectric substrate 205 is formed. The piezoelectric substrate 205 and the die-attach section 203 are coupled by bumps 206.

[0063] In the surface-acoustic-wave device 500 according to this embodiment, the distance Xλ between the centers

of adjacent electrode fingers of each of the reflectors 522 and 524 and the IDT 523 in the surface-acoustic-wave resonator 503 differs from the distance Yλ between the centers of adjacent electrode fingers of each of the reflectors 525 and 527 and the IDT 526 in the surface-acoustic-wave resonator 504. That is, the distance between the centers of the outermost electrode fingers of the IDT and the reflector differs between the surface-acoustic-wave resonators 503 and 504. λ is a wavelength determined by the electrode-finger pitch in the IDT of a surface-acoustic-wave filter. For example, in the surface-acoustic-wave resonator 503, Xλ = 0.57λ, and in the surface-acoustic-wave resonator 504, Yλ = 0.43λ.

[0064] A detailed example of the design of the longitudinally coupled resonator-type SAW filters 501 and 502 according to this embodiment is described below.

[0065] If the wavelength determined by the pitch of the electrode fingers in which the pitch of the electrode fingers is not made narrow is denoted as λI:

the finger overlap: 41.8λI,
the number of electrode fingers in the IDTs: (in the order of the IDT 505, the IDT 506, and the IDT 507): 18(3)/(3) 33(3)/(3)18 (the numerals within the parentheses indicate the number of electrode fingers in which the pitch is narrow),
the number of electrode fingers in the reflectors: 60 (reflectors 508 and 509), 90 (reflectors 513 and 514),
the duty ratio : 0.72 (IDT), 0.57 (reflector), and
the thickness of the electrode film: 0.092λI.

[0066] A detailed example of the design of the surface-acoustic-wave resonators 503 and 504 is described below:

the finger overlap: 16.5λI,
the number of electrode fingers in the IDTs: 180,
the number of electrode fingers in the reflectors: 15,
the duty ratio: 0.60, and
the thickness of electrode film: 0.093λI.

[0067] For comparison with respect to the surface-acoustic-wave device 500 according to this embodiment, the configuration of a surface-acoustic-wave device 1500 of comparative example 1 is shown in Fig. 18. As compared to the surface-acoustic-wave device 500, this surface-acoustic-wave device 1500 is configured in such a manner that the distance Xλ between the centers of adjacent electrode fingers (the outermost electrode-finger center-to-center distance) of each of the reflectors 522 and 524 and the IDT 523 in the surface-acoustic-wave resonator 503 is set as 0.50λ, and the distance Yλ between the centers of adjacent electrode fingers (the outermost electrode-finger center-to-center distance) of each of the reflectors 525 and 527 and the IDT 526 in the surface-acoustic-wave resonator 504 is set as 0.50λ. The other design parameters are identical to those of the surface-acoustic-wave device 500.

[0068] Figs. 16 and 17 show frequency - insertion loss characteristics, and frequency - common-mode attenuation characteristics in the surface-acoustic-wave device 500 according to this embodiment. Figs. 16 and 17 also show frequency - insertion loss characteristics, and frequency - common-mode attenuation characteristics in the surface-acoustic-wave device 1500 of comparative example 1.

[0069] When Fig. 17 is viewed, in the surface-acoustic-wave device 500 according to this embodiment, the common-mode attenuation in the vicinity of 1880 to 1900 MHz is approximately 22 dB, whereas in the surface-acoustic-wave device 1500 of comparative example 1, the common-mode attenuation is approximately 20 dB. That is, it can be seen that this common-mode attenuation is improved by approximately 2 dB. At this time, a large deterioration of the common-mode attenuation is not seen. Furthermore, as can be seen by viewing Fig. 16, a deterioration of insertion loss within the passband is also not seen. This is due to the effect that, since the distance Xλ between the centers of adjacent electrode fingers of each of the reflectors 522 and 524 and the IDT 523 in the surface-acoustic-wave resonator 503 differs from the distance Yλ between the centers of adjacent electrode fingers of each of the reflectors 525 and 527 and the IDT 526 in the surface-acoustic-wave resonator 504, the amplitude and phase characteristics in the surface-acoustic-wave resonator 503 differ from those in the surface-acoustic-wave resonator 504, and the deviation of the degree of balance at higher frequencies of the passband in the longitudinally coupled resonator-type SAW filters 501 and 502 is corrected.

[0070] Next, the range in which the common-mode attenuation is improved was studied. The study was made in such a manner that the distance Xλ between the centers of adjacent electrode fingers of each of the reflectors 522 and 524 and the IDT 523 in the surface-acoustic-wave resonator 503, and the distance Yλ between the centers of adjacent electrode fingers of each of the reflectors 525 and 527 and the IDT 526 in the surface-acoustic-wave resonator 504 are changed, and the common-mode attenuation at 1880 to 1900 MHz with respect to the difference between Xλ and Yλ was checked. The results are shown in Fig. 19. It can be seen from Fig. 19 that, until the difference between

$X\lambda$ and $Y\lambda$ is 0.18λ, common-mode attenuation which is larger than that in a case where $X\lambda$ and $Y\lambda$ are not made different (made identical) is obtained. That is, it can be seen that, in the surface-acoustic-wave device 500, preferably, $(0 + 0.5n)\lambda < |X - Y|\lambda \leq (0.18 + 0.5n)\lambda$, where n = 0, 1, 2...

[0071] As described in the foregoing, in the third embodiment, in the surface-acoustic-wave device having a balanced-to-unbalanced conversion function by using two longitudinally coupled resonator-type SAW filters 501 and 502 in which surface-acoustic-wave resonators are connected in series, the surface-acoustic-wave resonators 503 and 504 are connected in series between the longitudinally coupled resonator-type SAW filters 501 and 502, and the balanced signal terminal 515, respectively, and the distance between the centers of the outermost electrode fingers of the IDT and the reflector in each of the surface-acoustic-wave resonators 503 and 504 is made different. As a result, a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband is obtained.

[0072] Although in this embodiment, an example is described in which two longitudinally coupled resonator-type SAW filters having three IDTs are used, other arrangements are possible, for example two longitudinally coupled resonator-type SAW filters having five IDTs may be used. Furthermore, even when a surface-acoustic-wave device having a balanced-to-unbalanced conversion function is formed by using one longitudinally coupled resonator-type SAW filter, a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband is obtained by making different the distances between the centers of the outermost electrode fingers of the IDT and the reflectors of the surface-acoustic-wave resonator.

[0073] In this embodiment, as shown in Fig. 15, a surface-acoustic-wave device was manufactured by a method of making conduction between the package 200 and each electrode pad on the piezoelectric substrate 205 by means of a face-down technique using a bump-bonding technique. However, a wire-bonding technique may be used.

[0074] For the configuration in which the surface-acoustic-wave device is manufactured by a face-down technique, in addition to the configuration of Fig. 15, the surface-acoustic-wave device may be manufactured by a configuration in which, for example, as shown in Fig. 20, a piezoelectric substrate 302 is bonded onto a clustered substrate 301 by a flip-chip technique, this is sealed by covering with a resin 303, and this is cut in units of one package by dicing, or by a configuration in which, as shown in Fig. 21, similarly, a piezoelectric substrate 402 is bonded onto a clustered substrate 401 by a flip-chip technique, this is sealed by covering with a resin 403, and this is cut in units of one package by dicing. The positions where the clustered substrates 301 and 401 are diced are indicated generally by the dot-chain lines in Figs.20 and 21.

[0075] Although in this embodiment, a piezoelectric substrate formed from 40 ± 5° Y-cut X-propagation $LiTaO_3$ is used, in the present invention, as can be understood from the principle from which the effect is obtained, in addition to this piezoelectric substrate, the same advantages can be obtained by other piezoelectric substrates, such as, for example, 64° to 72° Y-cut X-propagation $LiNbO_3$ or 41° Y-cut X-propagation $LiNbO_3$.

[Fourth Embodiment]

[0076] A fourth embodiment of the present invention will now be described with reference to Figs. 22 to 25. For the sake of simplicity of description, components having the same function as that of the components shown in the third embodiment are designated with the same reference numerals, and accordingly, descriptions thereof are omitted here.

[0077] A surface-acoustic-wave device 500a according to this embodiment is configured in such a manner that, compared to the surface-acoustic-wave device 500 of the third embodiment, instead of the surface-acoustic-wave resonators 503 and 504, surface-acoustic-wave resonators 503a and 504a are used. The surface-acoustic-wave resonators 503a and 504a are configured in such a manner that reflectors 522a and 525a, and reflectors 524a and 527a are formed so as to sandwich IDTs 523a and 526a, respectively. In the surface-acoustic-wave resonators 503a and 504a, the ratio "a" of the pitch of the IDT 523a to the pitch of the reflectors 522a and 524a in the surface-acoustic-wave resonator 503a differs from the ratio "b" of the pitch of the IDT 526a to the pitch of the reflectors 525a and 527a in the surface-acoustic-wave resonator 504a. The pitch ratio is represented as "IDT pitch/reflector pitch". As an example, the pitch ratios of the IDT to the reflector in the surface-acoustic-wave resonators 503a and 504a are here set as a = 0.994 and b = 1.006, respectively. The other design parameters in the surface-acoustic-wave device 500a are identical to those of the surface-acoustic-wave device 1500 of comparative example 1 described above.

[0078] Figs. 23 and 24 show frequency - insertion loss characteristics, and frequency - common-mode attenuation characteristics in the surface-acoustic-wave device 500a according to this embodiment. Figs. 23 and 24 also show frequency - insertion loss characteristics, and frequency - common-mode attenuation characteristics in the surface-acoustic-wave device 1500 of comparative example 1.

[0079] When Fig. 24 is viewed, in the surface-acoustic-wave device 500a according to this embodiment, the common-mode attenuation in the vicinity of 1880 to 1900 MHz is approximately 22 dB, whereas in the surface-acoustic-wave device 1500 of comparative example 1, the common-mode attenuation is approximately 20 dB. That is, it can be seen that this common-mode attenuation is improved by approximately 2 dB. At this time, a large deterioration of the com-

mon-mode attenuation within the passband is not seen. Furthermore, as can be seen by viewing Fig. 23, a deterioration of insertion loss within the passband is also not seen. This is due to the effect that, since the pitch ratio of the IDT to the reflector is made different in the surface-acoustic-wave device 503a and the surface-acoustic-wave device 504a, the amplitude and phase characteristics in the surface-acoustic-wave device 503a and the surface-acoustic-wave device 504a differ, and the deviation of the degree of balance at higher frequencies of the passband in the longitudinally coupled resonator-type SAW filters 501 and 502 is corrected.

[0080] Next, the range in which the common-mode attenuation is improved was studied. The study was made in such a manner that the pitch ratio (a) of the IDT 523a to the reflectors 522a and 524a in the surface-acoustic-wave resonator 503a and the pitch ratio (b) of the IDT 526a to the reflectors 524a and 527a in the surface-acoustic-wave resonator 504a are changed, and the common-mode attenuation at 1880 to 1900 MHz with respect to the ratio of the pitch ratios (the pitch ratio of the surface-acoustic-wave resonator 503a/the pitch ratio of the surface-acoustic-wave resonator 504a (a/b)) was checked. The results are shown in Fig. 25. It can be seen from Fig. 25 that, when the ratio of the pitch ratios is approximately 0.984, common-mode attenuation which is larger than that in a case where the pitch ratio is not made different is obtained. That is, in the surface-acoustic-wave device 500, it can be seen that, preferably, the ratio of the pitch ratios is in the range of $0.984 \leq a/b < 1$.

[0081] As described in the foregoing, in the fourth embodiment, in a surface-acoustic-wave device having a balanced-to-unbalanced conversion function by using two longitudinally coupled resonator-type SAW filters 501 and 502 in which surface-acoustic-wave resonators are connected in series, the surface-acoustic-wave resonators 503a and 504a are connected in series between the longitudinally coupled resonator-type SAW filter 501 and the balanced signal terminal 515 and between the longitudinally coupled resonator-type SAW filter 502 and the balanced signal terminal 515, respectively, and the pitch ratio of the IDT to the reflector in each of the surface-acoustic-wave resonators 503a and 504a is made different. As a result, it is possible to obtain a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband.

[0082] In the surface-acoustic-wave device 500a according to this embodiment, although an example in which two longitudinally coupled resonator-type SAW filters having three IDTs are used is described, other arrangements are possible, for example the surface-acoustic-wave device 500a may be configured to use two longitudinally coupled resonator-type SAW filters having five IDTs. Furthermore, the surface-acoustic-wave device having a balanced-to-unbalanced conversion function may be configured by using one longitudinally coupled resonator-type SAW filter. Furthermore, a surface-acoustic-wave device having a balanced-to-unbalanced conversion function may be configured by using a surface-acoustic-wave filter in which at least one IDT is divided in the direction of the propagation of the surface-acoustic wave or in the direction of the finger overlap. In the above-described configuration, by making the pitch ratio of the IDT to the reflector in each surface-acoustic-wave resonator different from that in the other resonator, a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband can be obtained.

[Fifth Embodiment]

[0083] A fifth embodiment of the present invention will now be described below with reference to Figs. 26 to 29. For the sake of simplicity of description, components having the same function as that of the components shown in the third and fourth embodiments are designated with the same reference numerals, and accordingly, descriptions thereof are omitted here.

[0084] A surface-acoustic-wave device 500b according to this embodiment is configured in such a manner that, compared to the surface-acoustic-wave device 500 of the third embodiment, instead of the surface-acoustic-wave resonators 503 and 504, surface-acoustic-wave resonators 503b and 504b are used. The surface-acoustic-wave resonators 503b and 504b are configured in such a manner that reflectors 522b and 525b, and reflectors 524b and 527b are formed so as to sandwich IDTs 523b and 526b, respectively. In the surface-acoustic-wave resonators 503b and 504b, the duty ratios of the IDT 523b and the reflectors 522b and 524b in the surface-acoustic-wave resonator 503b differ from the duty ratios of the IDT 526b and the reflectors 525b and 527b in the surface-acoustic-wave resonator 504b. The duty ratios in the surface-acoustic-wave resonators 503b and 504b are set to 0.620 and 0.580, respectively. The other design parameters in the surface-acoustic-wave device 500b are identical to those of the surface-acoustic-wave device 1500 in comparative example 1 described above.

[0085] Figs. 27 and 28 show frequency - insertion loss characteristics, and frequency - common-mode attenuation characteristics in the surface-acoustic-wave device 500b according to this embodiment. Figs. 27 and 28 also show frequency - insertion loss characteristics, and frequency - VSWR characteristics in the surface-acoustic-wave device 1500 of comparative example 1.

[0086] When Fig. 28 is viewed, in the surface-acoustic-wave device 500b according to this embodiment, the common-mode attenuation in the vicinity of 1880 to 1900 MHz is approximately 22 dB, whereas in the surface-acoustic-wave device 1500 of comparative example 1, the common-mode attenuation is approximately 20 dB. That is, it can be seen

that this common-mode attenuation is improved by approximately 2 dB. At this time, a large deterioration of the common-mode attenuation within the passband is not seen. Furthermore, as can be seen by viewing Fig. 27, a deterioration of insertion loss within the passband is also not seen. This is due to the effect that, since the duty ratios of the IDT and the reflector in the surface-acoustic-wave resonators 503b and 504b are made different, the amplitude and phase characteristics in the surface-acoustic-wave resonators 503b and 504b differ, and the deviation of the degree of balance at higher frequencies of the passband in the longitudinally coupled resonator-type SAW filters 501 and 502 is corrected.

[0087] Next, the range in which the common-mode attenuation is improved was studied. The study was made in such a manner that the duty ratios (x) of the IDT 523b and the reflectors 522b and 524b in the surface-acoustic-wave resonator 503b and the duty ratios (y) of the IDT 526b and the reflectors 525b and 527b in the surface-acoustic-wave resonator 504b are changed, and the common-mode attenuation at 1880 to 1900 MHz with respect to the difference (x - y) between these duty ratios was checked. The results are shown in Fig. 29. It can be seen from Fig. 29 that, until the difference between the duty ratios is approximately 0.05, common-mode attenuation which is larger than that in a case where the duty ratios of the surface-acoustic-wave resonators 503b and 504b are not made different is obtained. That is, in the surface-acoustic-wave device 500b, it can be seen that, preferably, the duty ratio is in the range of $0 \leq |x - y| < 0.05$.

[0088] As described in the foregoing, in the fifth embodiment, in the surface-acoustic-wave device having a balanced-to-unbalanced conversion function by using two longitudinally coupled resonator-type SAW filters 501 and 502 in which surface-acoustic-wave resonators are connected in series, the surface-acoustic-wave resonators 503a and 504a are connected in series between the longitudinally coupled resonator-type SAW filters 501 and the balanced signal terminal 515 and between the longitudinally coupled resonator-type SAW filters 502 and the balanced signal terminal 515, respectively, and the duty ratios of the IDT and the reflector in each of the surface-acoustic-wave resonators 503a and 504a are made different. As a result, it is possible to obtain a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband.

[0089] Furthermore, in the surface-acoustic-wave device 500b, among the duty ratios of the IDT 523b and the reflectors 522b and 524b in the surface-acoustic-wave resonator 503b, and the duty ratios of the IDT 526b and the reflectors 525b and 527b in the surface-acoustic-wave resonator 504b, the duty ratio of only the IDT of the surface-acoustic-wave resonator or the duty ratio of only the reflector of the surface-acoustic-wave resonator may be made different. The same advantages can also be obtained in these configurations.

[0090] In the surface-acoustic-wave device 500b according to the fifth embodiment, although an example is described in which two longitudinally coupled resonator-type SAW filters having three IDTs are used is described, the surface-acoustic-wave device 500b may be configured differently, for example it may be configured to use two longitudinally coupled resonator-type SAW filters having five IDTs. Furthermore, a surface-acoustic-wave device having a balanced-to-unbalanced conversion function may be configured by using one longitudinally coupled resonator-type SAW filter. Furthermore, a surface-acoustic-wave device having a balanced-to-unbalanced conversion function may be configured by using a surface-acoustic-wave filter in which at least one IDT is divided in the direction of the propagation of the surface-acoustic wave or in the direction of the finger overlap. In the above-described configuration, by making the duty ratio of the IDT and the duty ratio of the reflector in each surface-acoustic-wave resonator different from each other, a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband can be obtained.

[0091] Furthermore, for example, by making different at least two of the following: the distance between the centers of the outermost electrode fingers of the reflector and the IDT, the ratio of the pitch ratio of the reflector to the pitch ratio of the IDT, and the duty ratios of the reflector and the IDT in each of the surface-acoustic-wave resonators 503 and 504 of comparative example 1, it is also possible to obtain a surface-acoustic-wave device having a large common-mode attenuation at higher frequencies of the passband.

[0092] Next, a communications device using a surface-acoustic-wave (SAW) device according to the above-described embodiments will now be described with reference to Fig. 11. The communications device 600 comprises, on the receiver side (the Rx side) for performing reception, an antenna 601, an antenna duplexer section/RF Top filter 602, an amplifier 603, an Rx interstage filter 604, a mixer 605, a 1st IF filter 606, a mixer 607, a 2nd IF filter 608, a 1st + 2nd IF local synthesizer 611, a TCXO (temperature compensated crystal oscillator) 612, a divider 613, and a local filter 614.

[0093] It is preferable that transmission be performed from the Rx interstage filter 604 to the mixer 605 using balanced signals in order to ensure balanced characteristics, as indicated by two lines in Fig. 11.

[0094] The communications device 600 commonly uses the antenna 601 and the antenna duplexer section/RF Top filter 602, and comprises, on the transmission side (the Tx side) for performing transmission, a Tx IF filter 621, a mixer 622, a Tx interstage filter 623, an amplifier 624, a coupler 625, an isolator 626, an APC (automatic power control) 627.

[0095] The SAW device described in the above-described embodiments can be suitably used in the Rx interstage filter 604, the 1st IF filter 606, the Tx IF filter 621, and the Tx interstage filter 623.

[0096] The SAW device according to the present invention can have a filter function and an unbalanced-to-balanced

conversion function, and moreover, has superior characteristics such that the amplitude characteristics between balanced signals are closer to the ideal amplitude characteristics. Therefore, the communications device of the present invention, having the SAW device, can improve transmission characteristics.

[0097] The present invention is not limited to each of the above-described embodiments, and various modifications are possible within the scope described in the claims. An embodiment obtained by appropriately combining technical means disclosed in different embodiments is included in the technical scope of the present invention.

Claims

1. A surface-acoustic-wave device comprising:

   a first surface-acoustic-wave element (1) having a plurality of interdigital transducers (11-13) formed along the propagation direction of a surface-acoustic wave; and
   a second surface-acoustic-wave element (2) having a plurality of interdigital transducers (21-23) formed along the propagation direction of a surface-acoustic wave, said surface-acoustic-wave device having an unbalanced-to-balanced conversion function with the phase of said second surface-acoustic-wave element (2) being reversed by 180° with respect to said first surface-acoustic-wave element (1),

   wherein a first resonator (3) is connected in series to the unbalanced side of said first surface-acoustic-wave element (1), and a second resonator (4) is connected in series to the unbalanced side of said second surface-acoustic-wave element (2), and the first resonator (3) and the second resonator (4) are formed with different design parameters.

2. A surface-acoustic-wave device according to Claim 1, wherein said first resonator (3) and said second resonator (4) are surface-acoustic-wave resonators including at least one interdigital transducer (31/41) and a reflector (32/42) arranged so as to sandwich the interdigital transducer.

3. A surface-acoustic-wave device according to Claim 1 or 2, wherein said design parameters are the numbers of electrode fingers in said first resonator (3) and said second resonator (4).

4. A surface-acoustic-wave device according to Claim 1 or 2, wherein said design parameters are finger overlaps in said first resonator (3) and said second resonator (4).

5. A surface-acoustic-wave device according to Claim 1 or 2, wherein said design parameters are duty ratios of a reflector (32/42) and/or an interdigital transducer (31/41) in said first resonator (3) and said second resonator (4).

6. A surface-acoustic-wave device according to Claim 5, wherein, when the duty ratio of a reflector (32) and/or an interdigital transducer (31) in said first resonator (3) is represented as x and the duty ratio of a reflector (42) and/ or an interdigital transducer (41) in said second resonator (4) is represented as y, the relation $0 < |x - y| \leq 0.05$ is satisfied.

7. A surface-acoustic-wave device according to Claim 1 or 2, wherein said design parameters are the distances between the centers of the outermost electrode fingers of the reflectors (32/42) and the interdigital transducer (31/41) in said first resonator (3) and said second resonator (4).

8. A surface-acoustic-wave device according to Claim 7, wherein, when the wavelength determined by the structure of the interdigital transducer of said surface-acoustic-wave element is denoted as λ, and the distance between the centers of the outermost electrode fingers of the reflector (32) and the interdigital transducer (31) in said first resonator (3) is denoted as $X\lambda$ and the distance between the centers of the outermost electrode fingers of the reflector (42) and the interdigital transducer (41) of said second resonator (4) is denoted as $Y\lambda$, the relation $(0 + 0.5n)\lambda < |X - Y| \lambda \leq (0.18 + 0.5n)\lambda$, where n = 0, 1, 2..., is satisfied.

9. A surface-acoustic-wave device according to Claim 1 or 2, wherein said design parameters are the pitch ratios of the reflector (32/420 and the interdigital transducer (31/41) in said first resonator (3) and said second resonator (4).

10. A surface-acoustic-wave device according to Claim 9, wherein, when the pitch ratios of the reflector and the interdigital transducer (pitch of the interdigital transducer/pitch of the reflector) in said first resonator (3) and said second

resonator (4) are denoted as a and b, respectively, the relation $0.984 \leq a/b < 1$ is satisfied.

11. A surface-acoustic-wave device according to any previous Claim, wherein said surface-acoustic-wave device is housed in a package by a face-down technique.

12. A communications device comprising a surface-acoustic-wave device according to any previous Claim.

FIG. 1

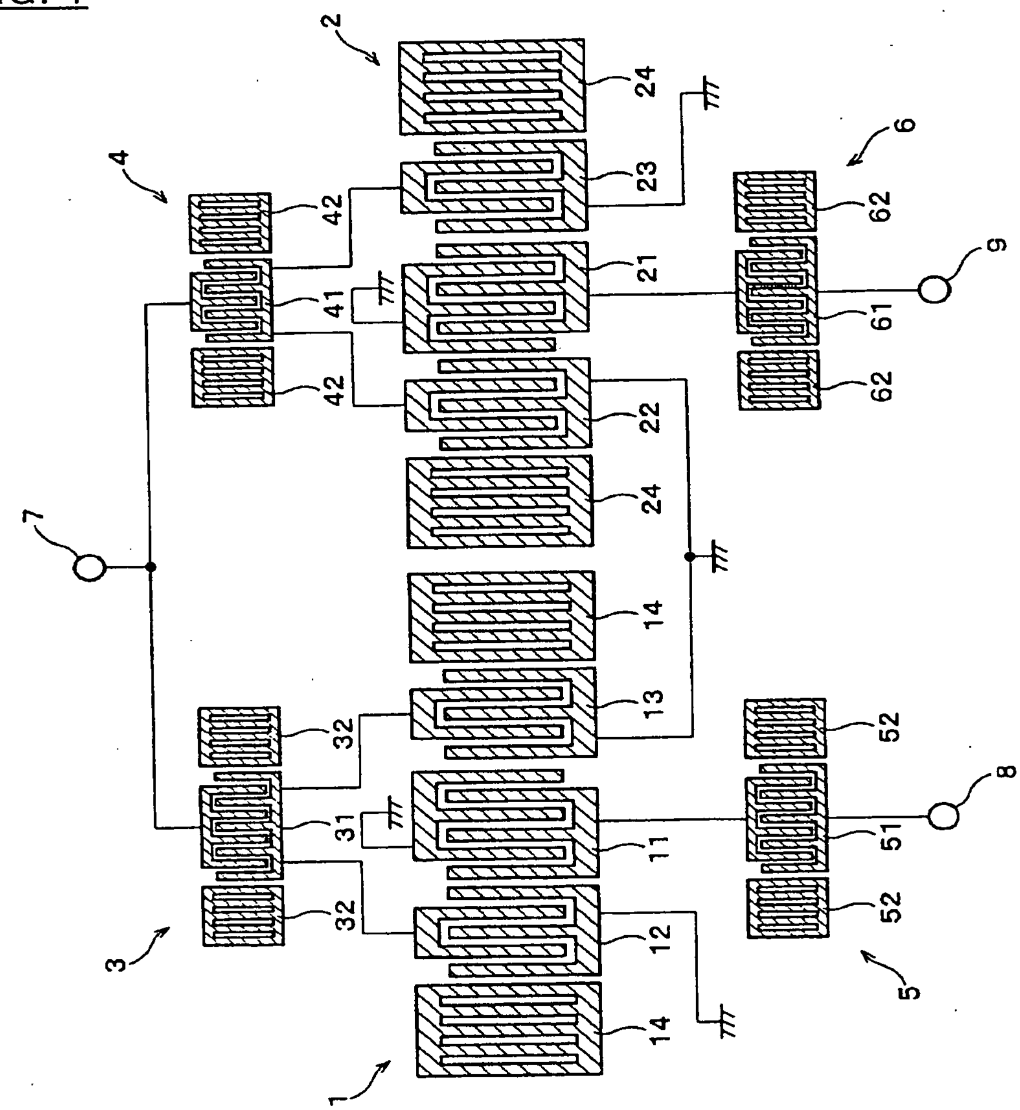

2
24
23
21
22
24
14
13
11
12
14
1
4
42
41
42
3
32
31
32
6
62
61
62
9
5
52
51
52
8
7

FIG. 2

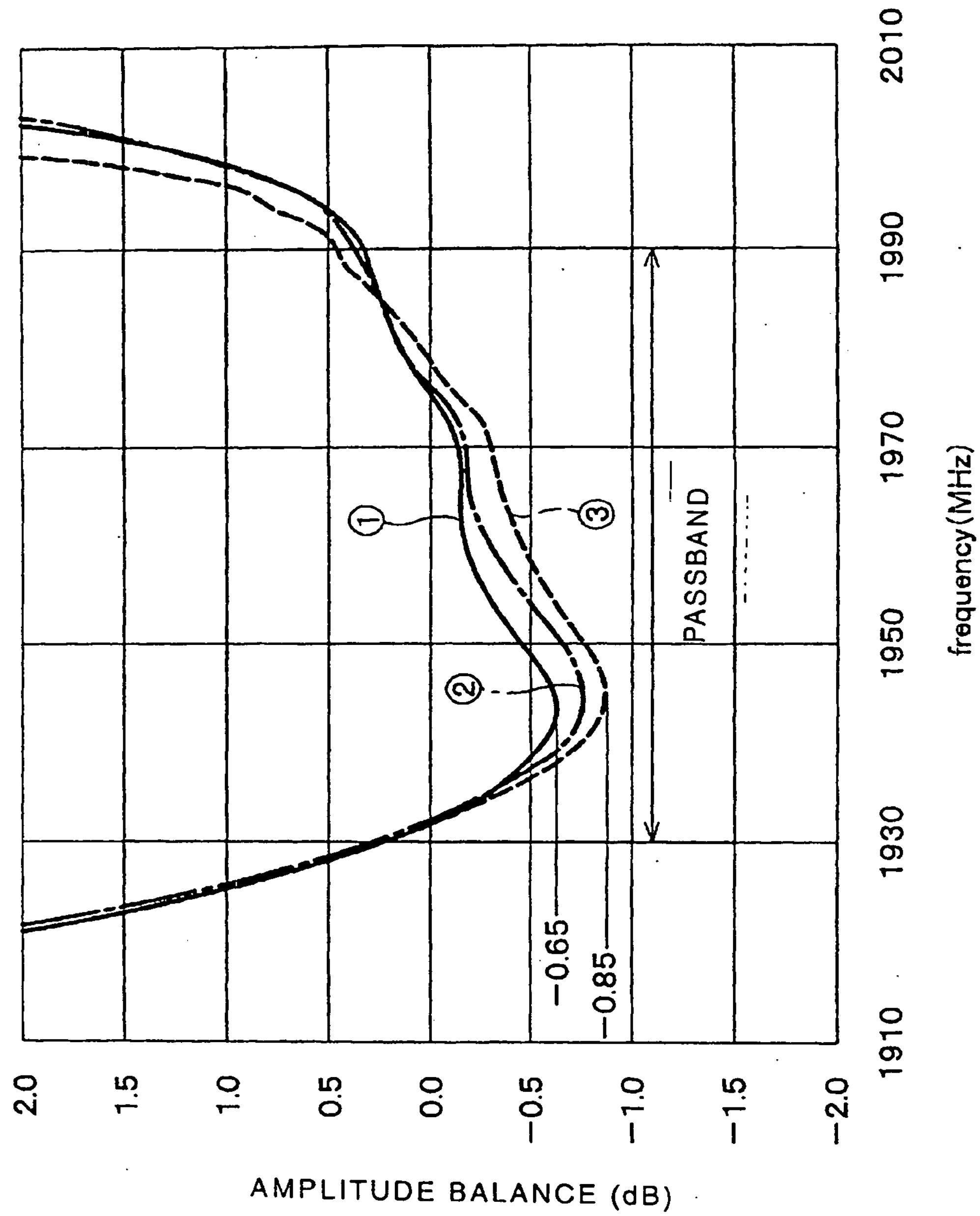

AMPLITUDE BALANCE (dB)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
frequency (MHz)
1910
1930
1950
1970
1990
2010
PASSBAND
−0.65
−0.85
1
2
3

FIG. 3

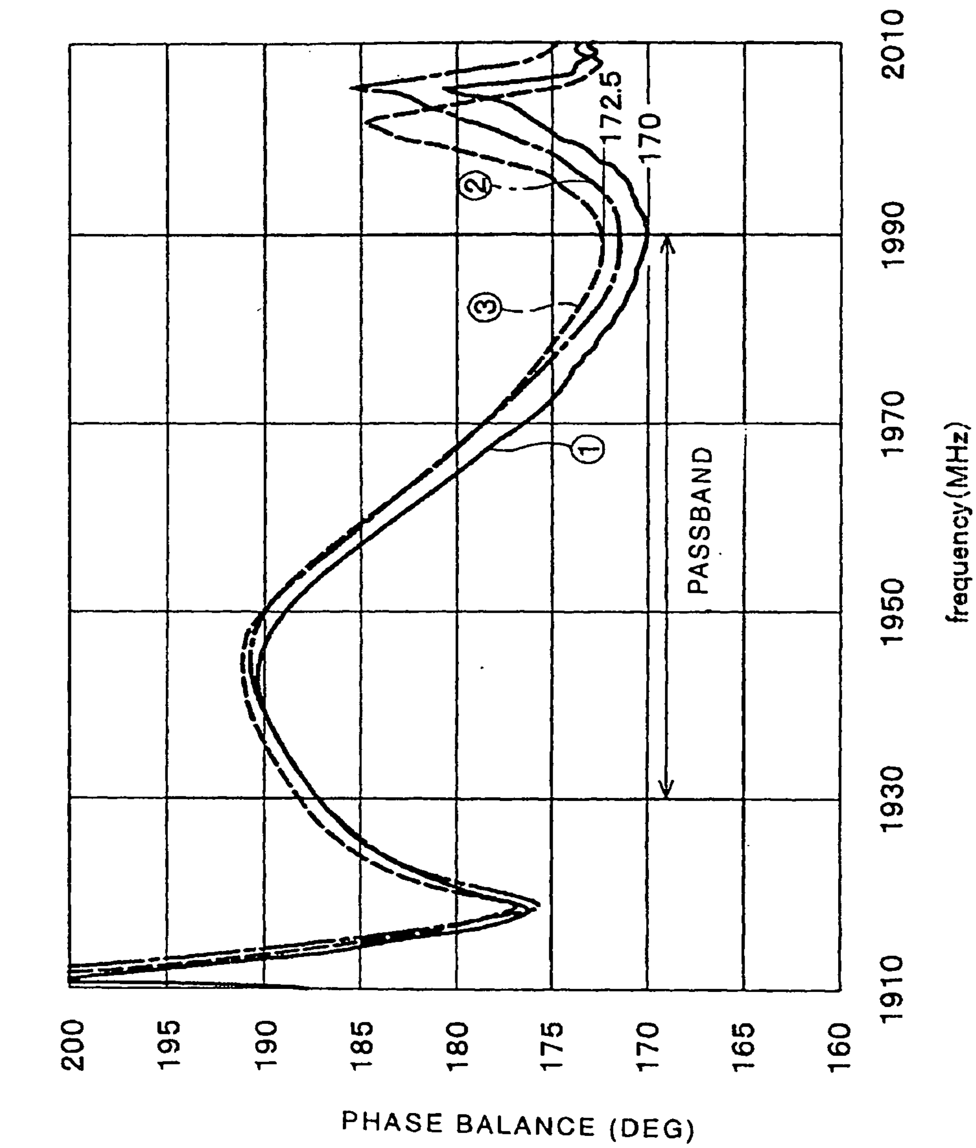

PHASE BALANCE (DEG)
200
195
190
185
180
175
170
165
160
frequency(MHz)
1910
1930
1950
1970
1990
2010
PASSBAND
172.5
170
1
2
3

FIG. 4

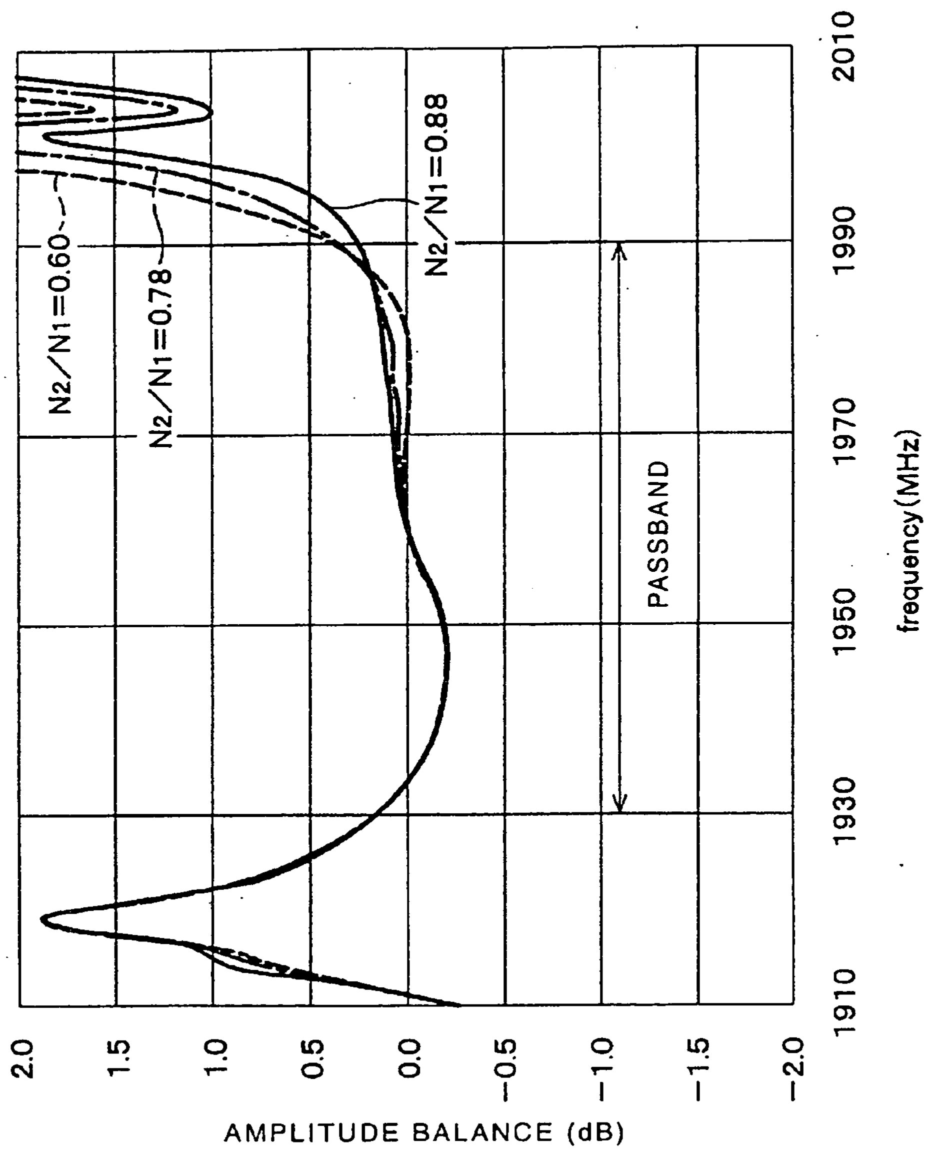

N2/N1=0.60
N2/N1=0.78
N2/N1=0.88
PASSBAND
frequency(MHz)
1910
1930
1950
1970
1990
2010
AMPLITUDE BALANCE (dB)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

FIG. 5

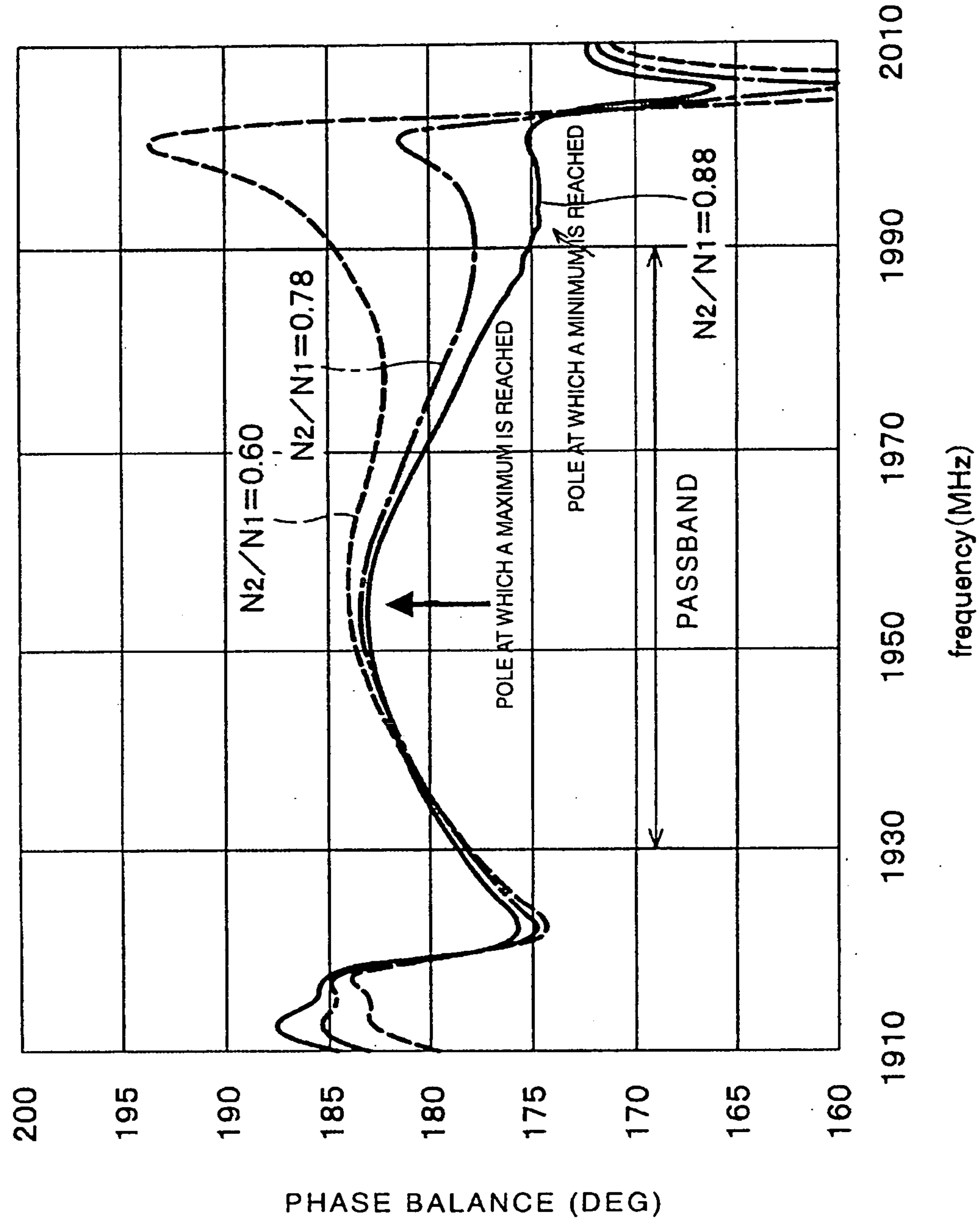

PHASE BALANCE (DEG)
200
195
190
185
180
175
170
165
160
frequency(MHz)
1910
1930
1950
1970
1990
2010
N2/N1=0.60
N2/N1=0.78
N2/N1=0.88
POLE AT WHICH A MAXIMUM IS REACHED
POLE AT WHICH A MINIMUM IS REACHED
PASSBAND

FIG. 6

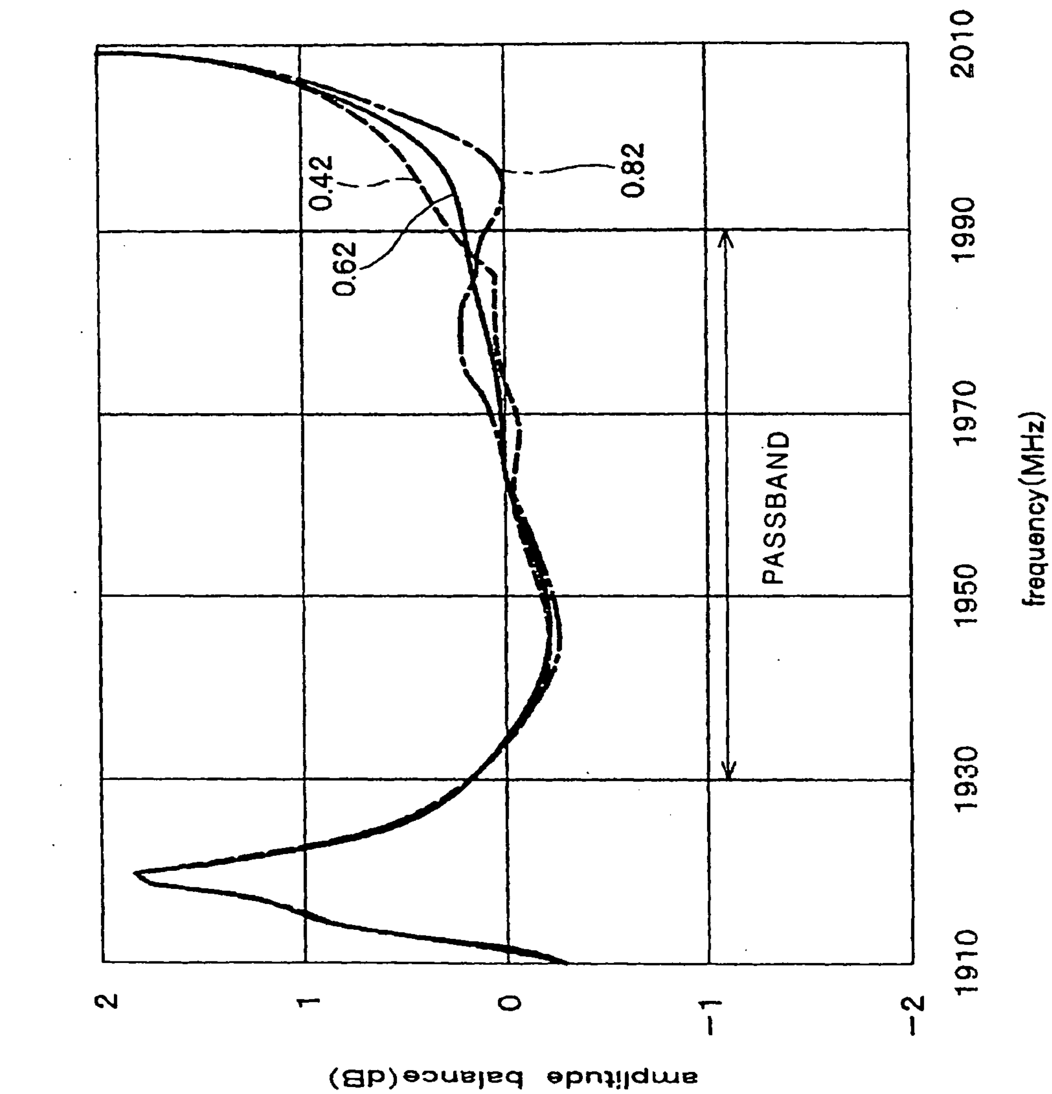

0.42
0.62
0.82
PASSBAND
1910
1930
1950
1970
1990
2010
frequency(MHz)
2
1
0
−1
−2
amplitude balance(dB)

FIG. 7

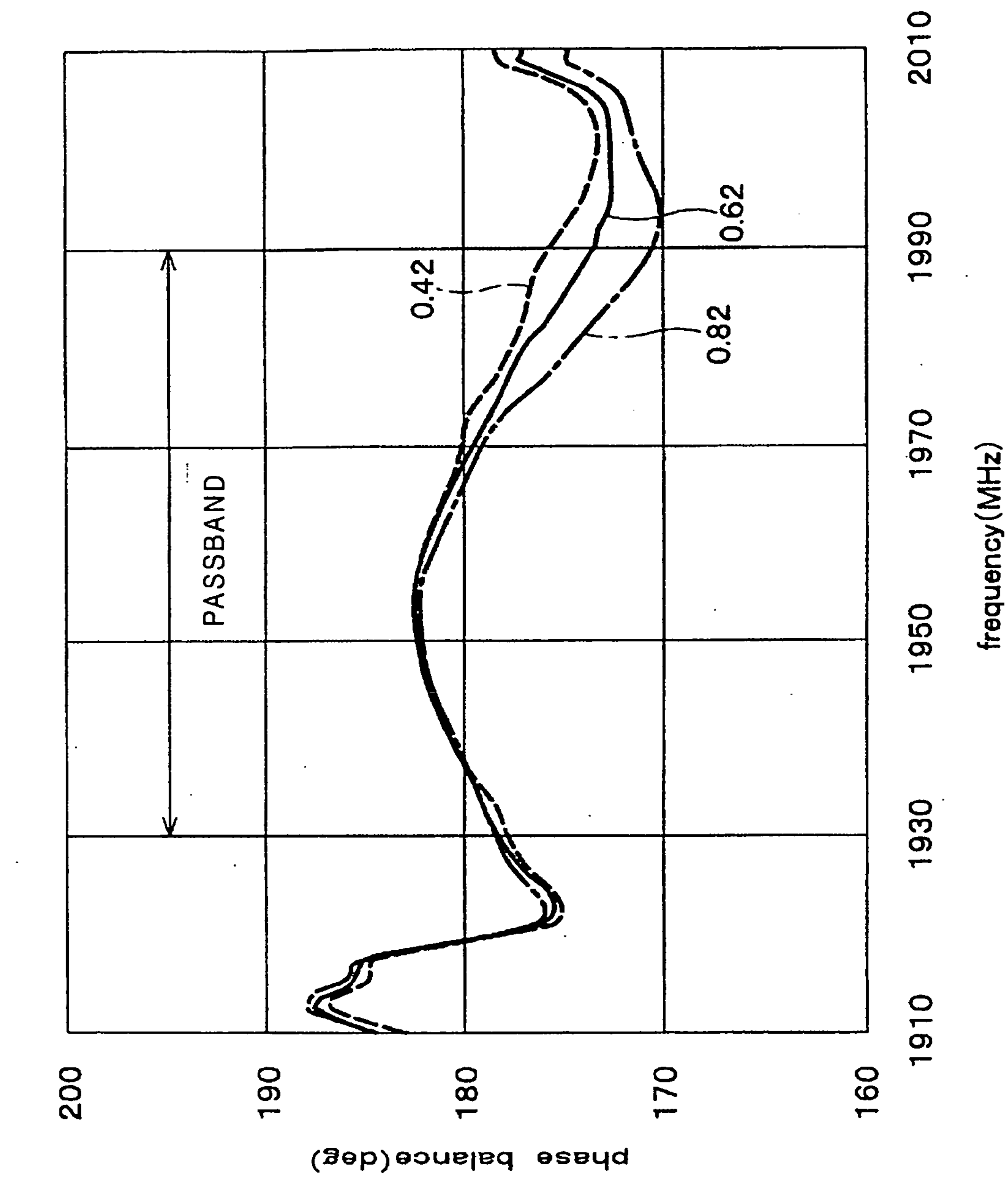

PASSBAND
0.42
0.62
0.82
200
190
180
170
160
phase balance(deg)
1910
1930
1950
1970
1990
2010
frequency(MHz)

FIG. 8

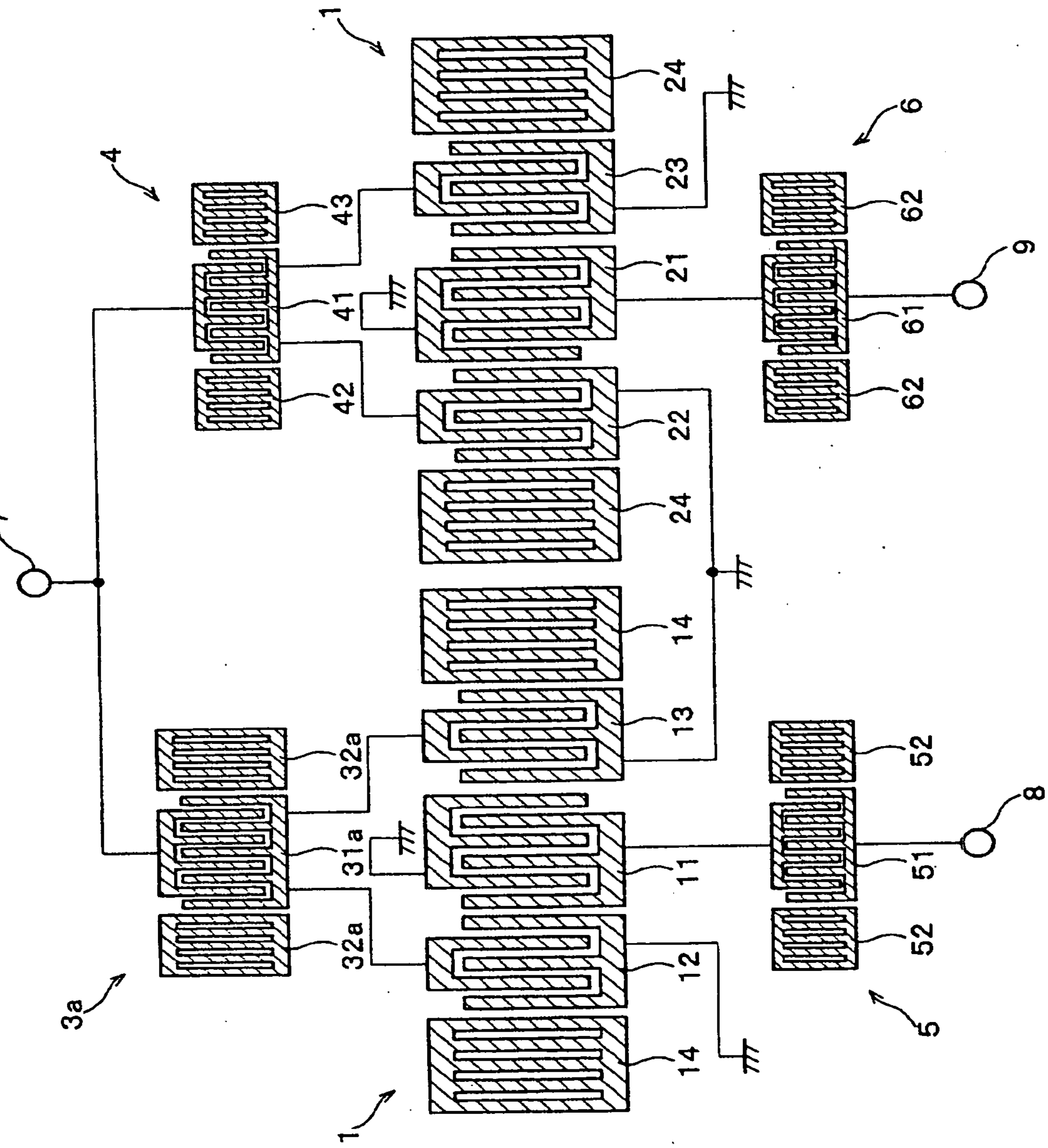

1
24
23
21
22
24
6
62
9
61
62
4
43
41
42
7
14
13
11
12
14
1
32a
31a
32a
3a
52
8
51
52
5

FIG. 9

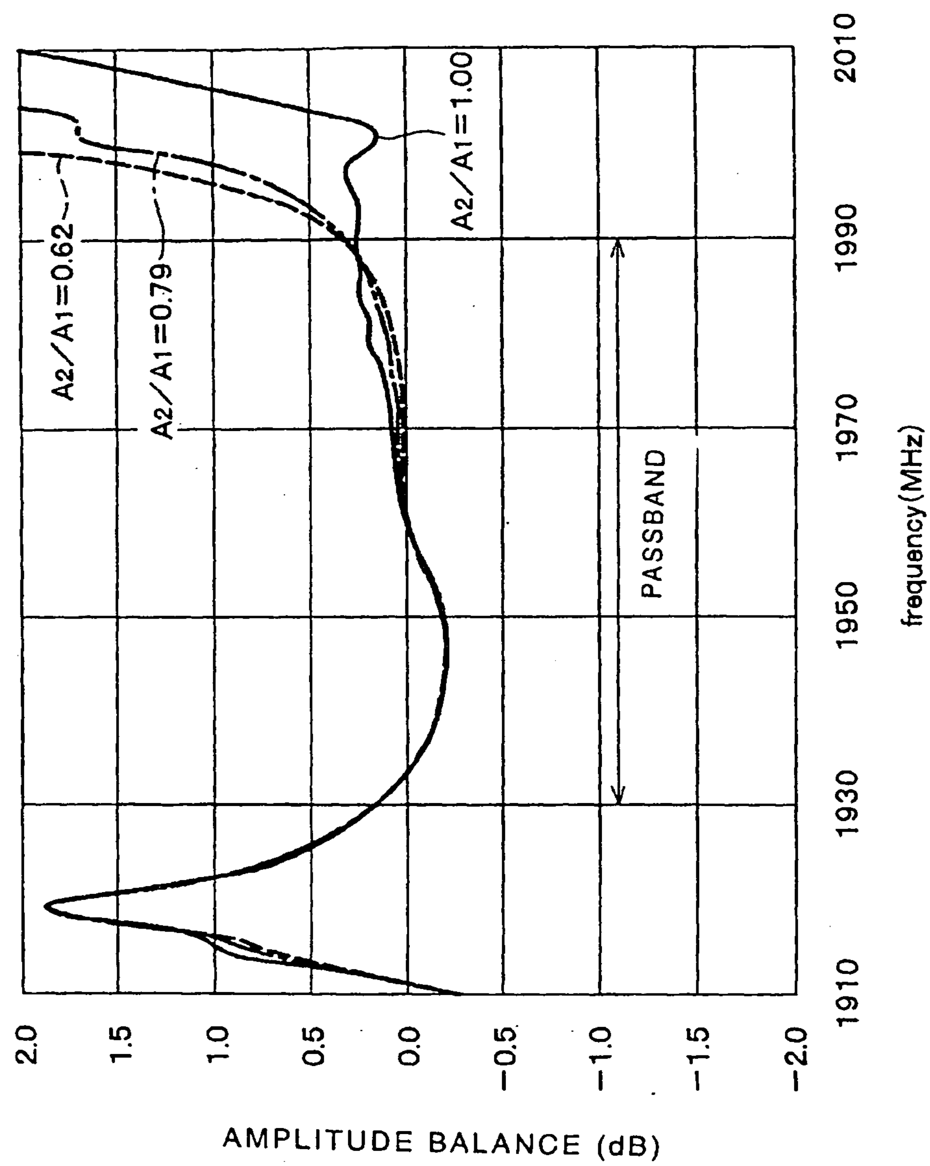

A2/A1=1.00
A2/A1=0.62
A2/A1=0.79
PASSBAND
frequency(MHz)
AMPLITUDE BALANCE (dB)
1910
1930
1950
1970
1990
2010
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

FIG. 10

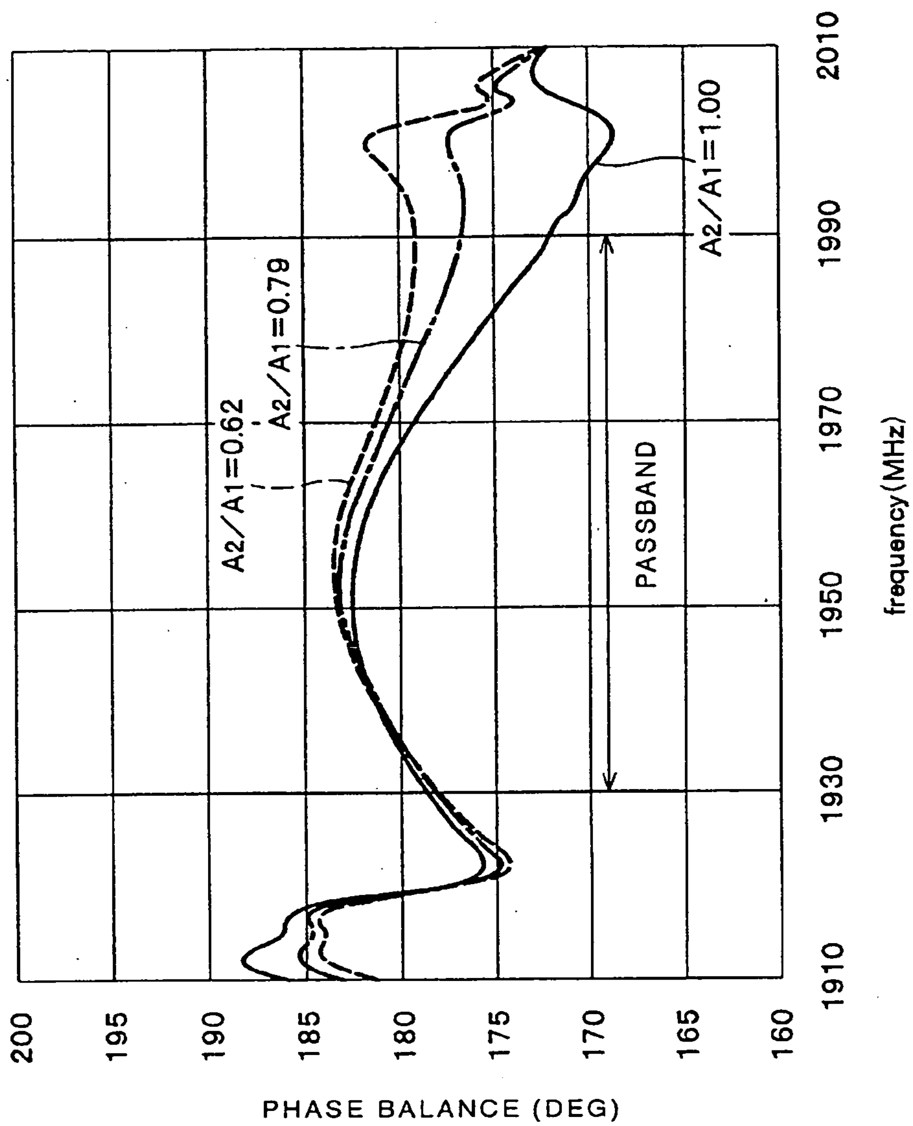

A2/A1=0.62
A2/A1=0.79
A2/A1=1.00
PASSBAND
200
195
190
185
180
175
170
165
160
PHASE BALANCE (DEG)
1910
1930
1950
1970
1990
2010
frequency(MHz)

FIG. 11

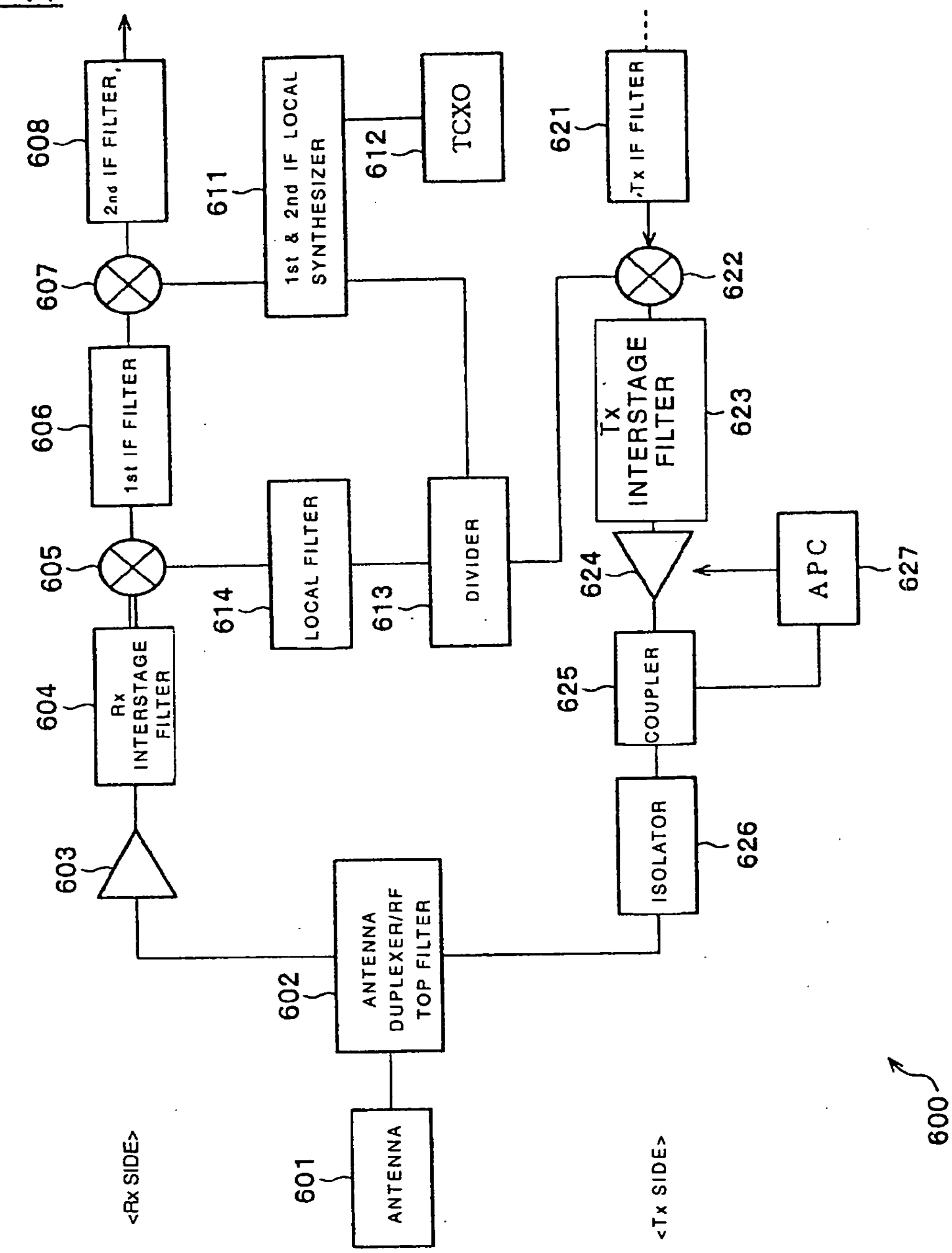

2nd IF FILTER
608
1st & 2nd IF LOCAL SYNTHESIZER
611
TCXO
612
Tx IF FILTER
621
607
1st IF FILTER
606
LOCAL FILTER
614
DIVIDER
613
622
Tx INTERSTAGE FILTER
623
605
624
APC
627
Rx INTERSTAGE FILTER
604
COUPLER
625
603
ISOLATOR
626
ANTENNA DUPLEXER/RF TOP FILTER
602
<Rx SIDE>
ANTENNA
601
<Tx SIDE>
600

FIG. 12

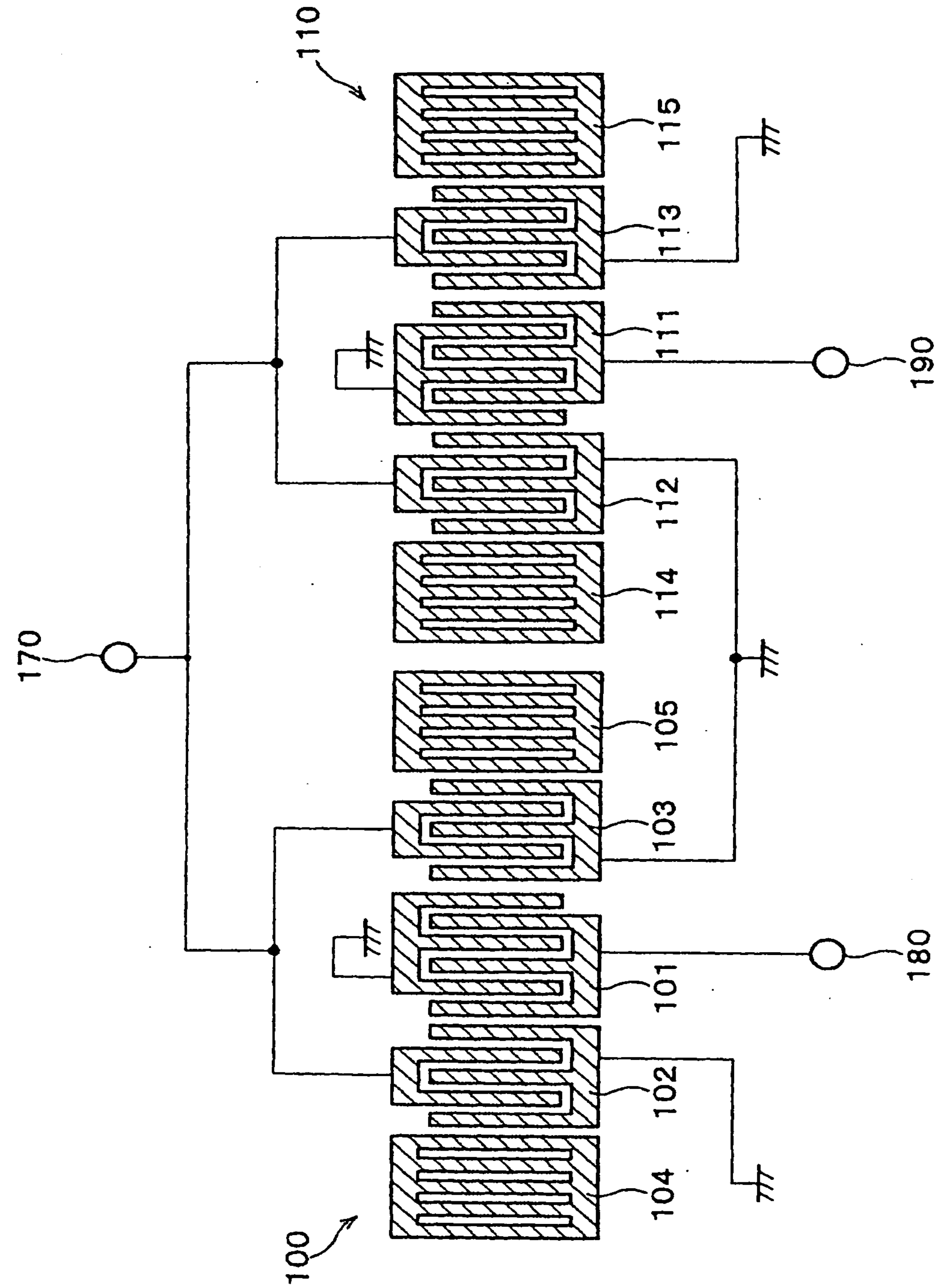
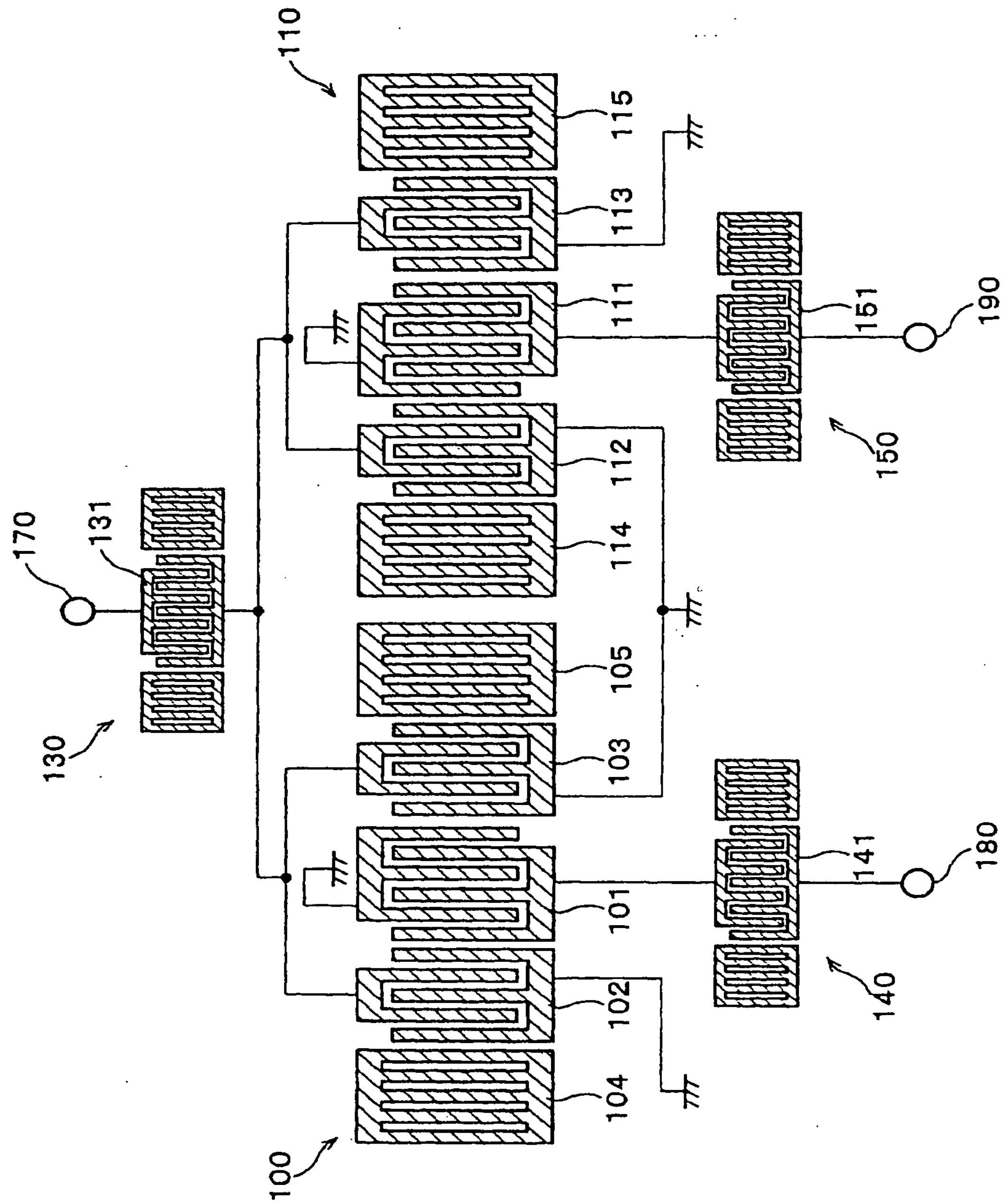


FIG. 13



110
115
113
111
151
190
112
150
114
170
131
105
103
130
101
141
180
102
140
104
100

FIG. 14

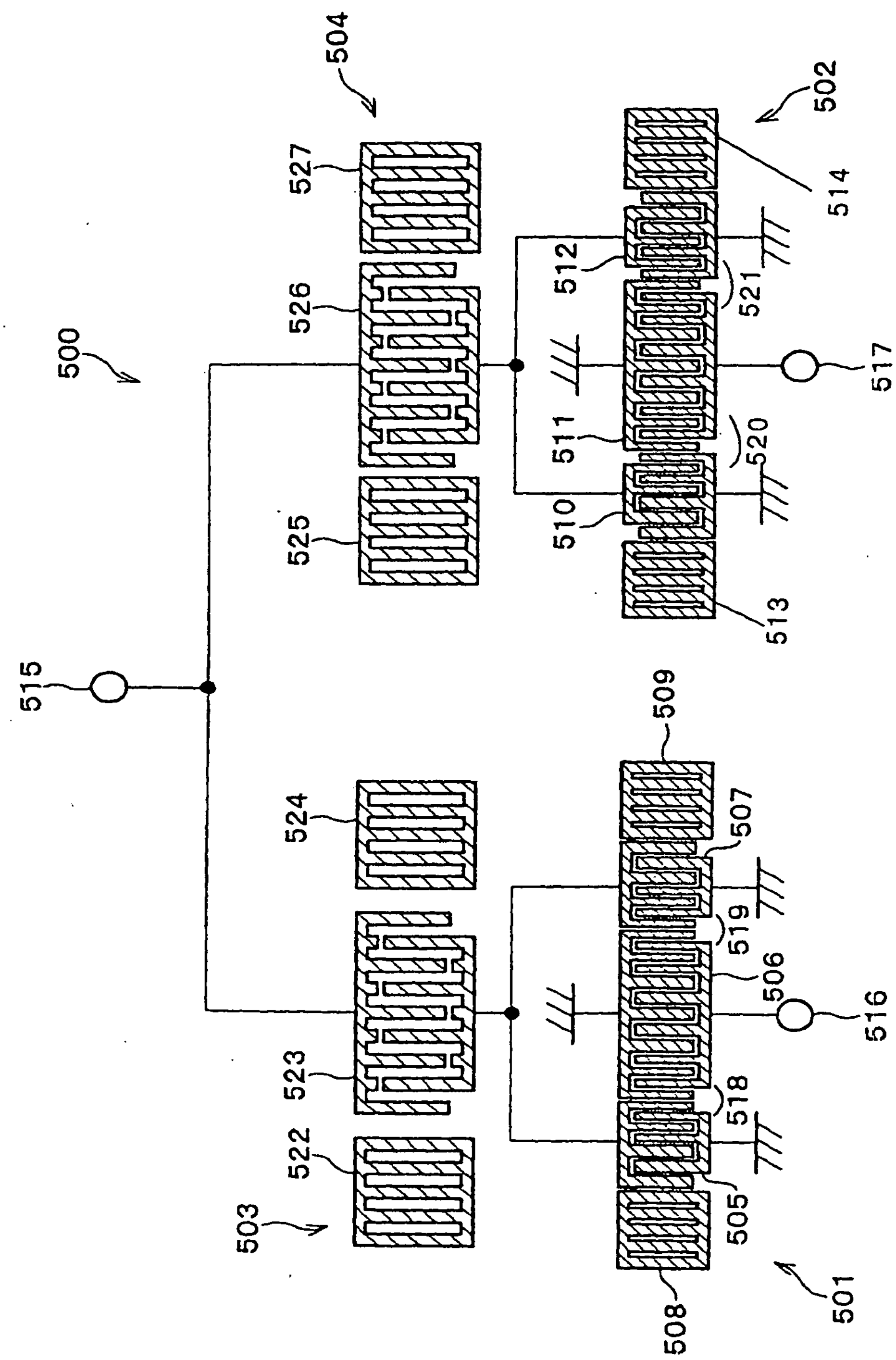

500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527

FIG. 15

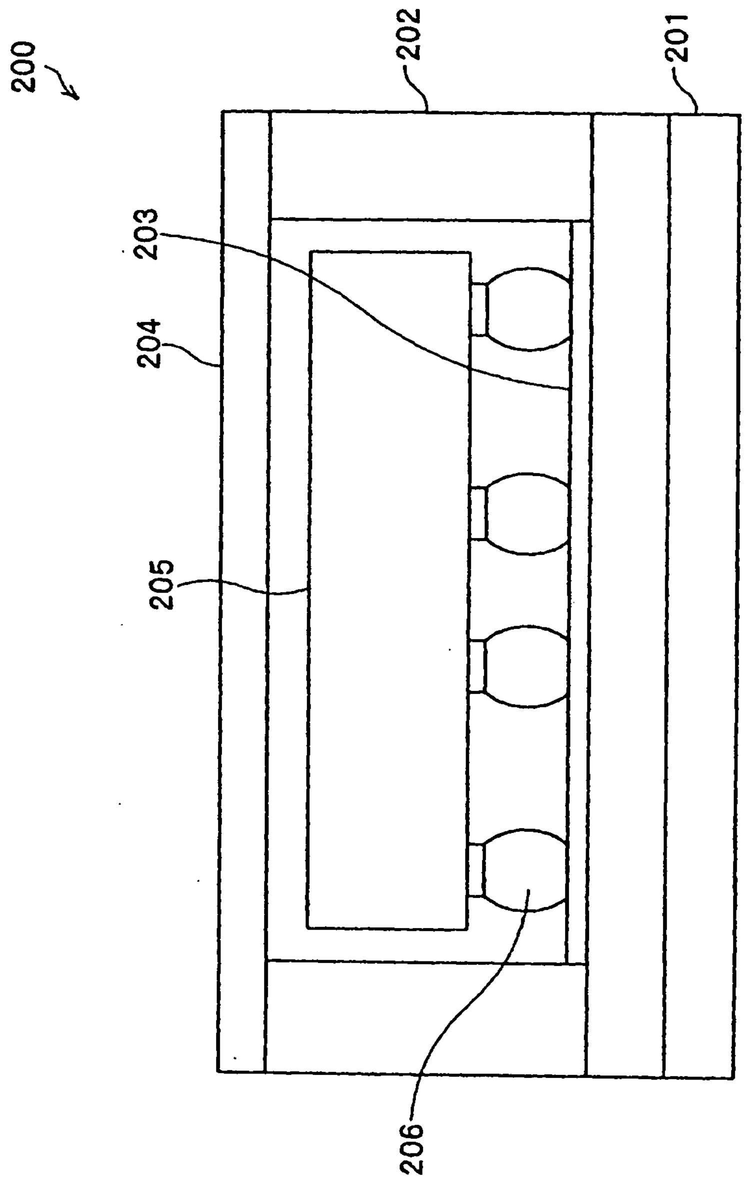


FIG. 16

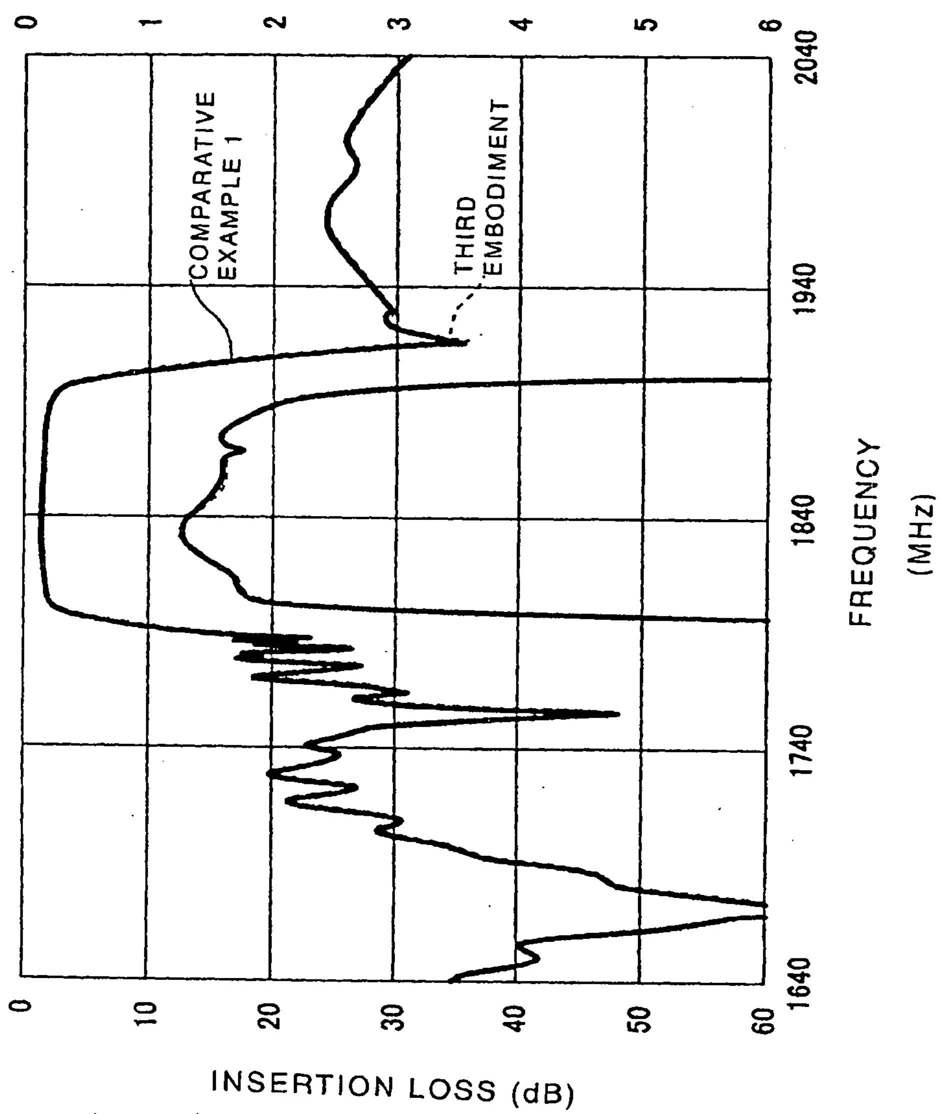

COMPARATIVE EXAMPLE 1
THIRD EMBODIMENT
FREQUENCY (MHz)
INSERTION LOSS (dB)
1640
1740
1840
1940
2040
0
10
20
30
40
50
60
0
1
2
3
4
5
6

FIG. 17

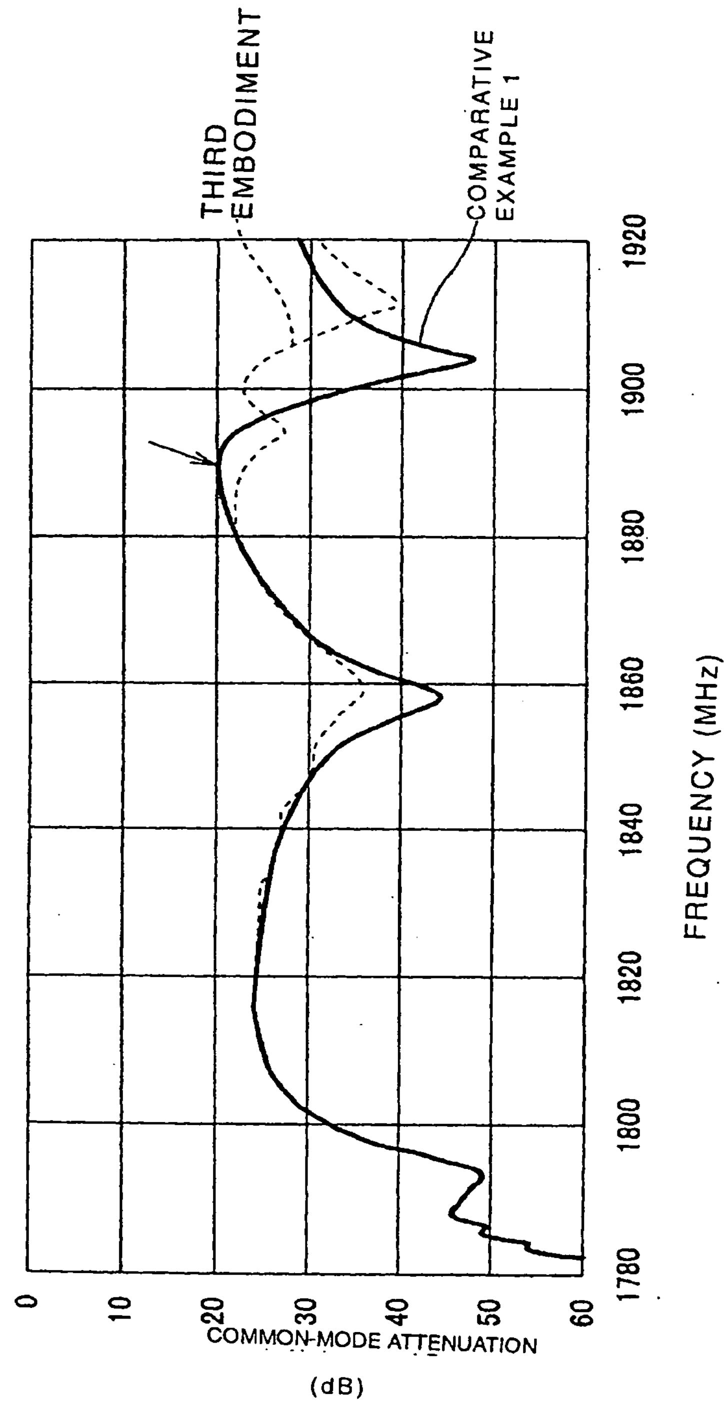

THIRD
EMBODIMENT
COMPARATIVE
EXAMPLE 1
1780
1800
1820
1840
1860
1880
1900
1920
FREQUENCY (MHz)
0
10
20
30
40
50
60
COMMON-MODE ATTENUATION
(dB)

FIG. 18

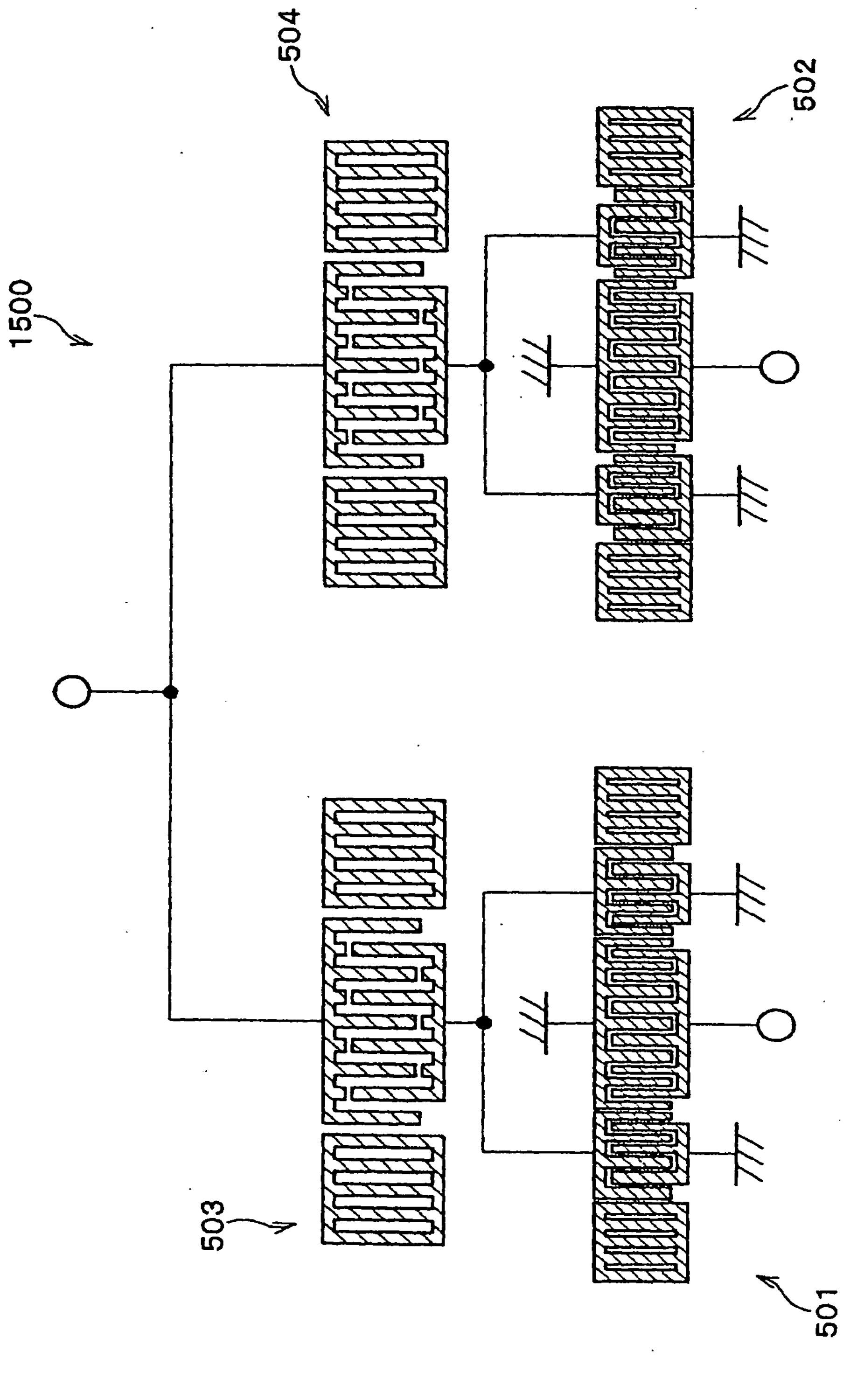


FIG. 19

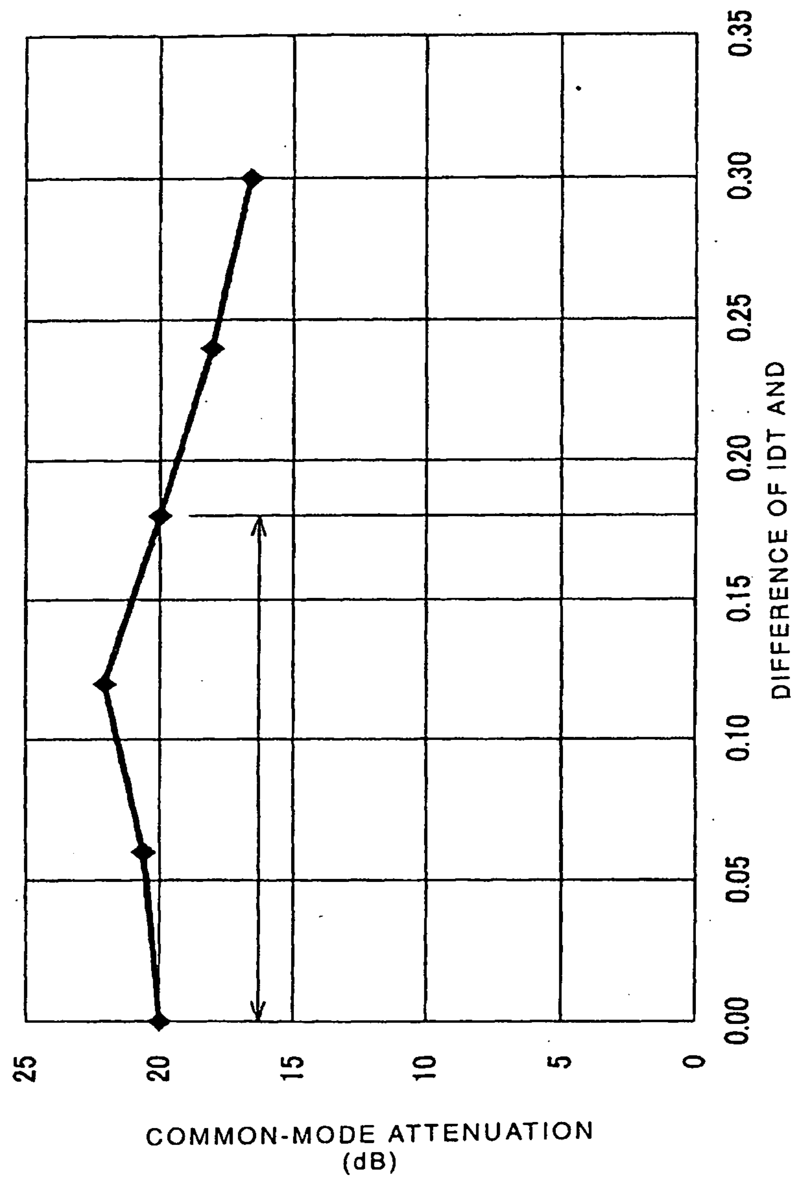

0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
DIFFERENCE OF IDT AND
REFLECTOR SPACING (λ)
25
20
15
10
5
0
COMMON-MODE ATTENUATION
(dB)

FIG. 20

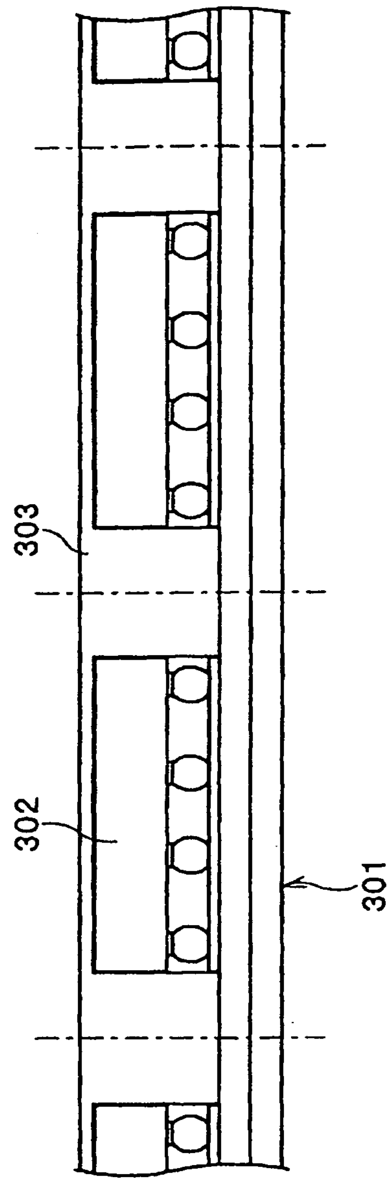


FIG. 21

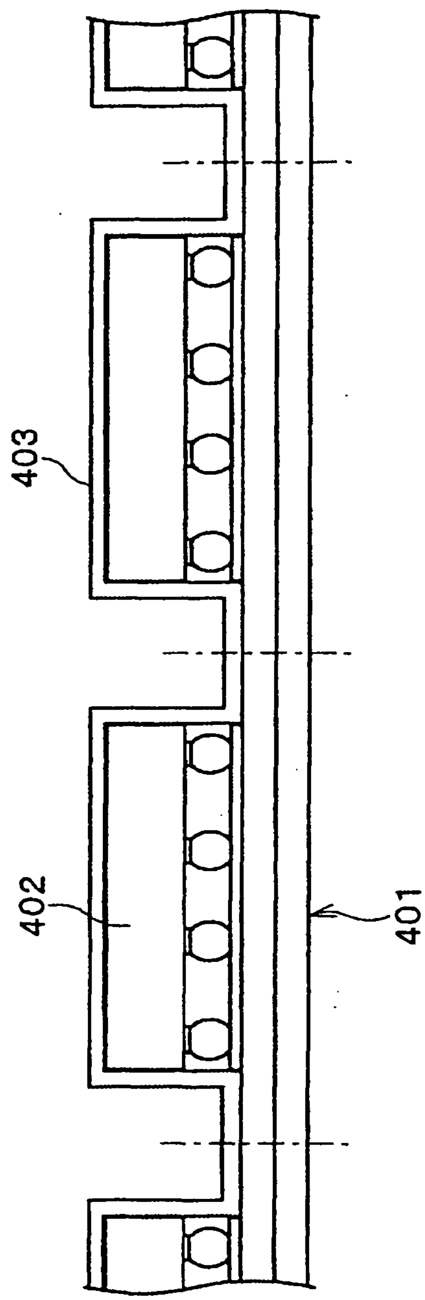


FIG. 22

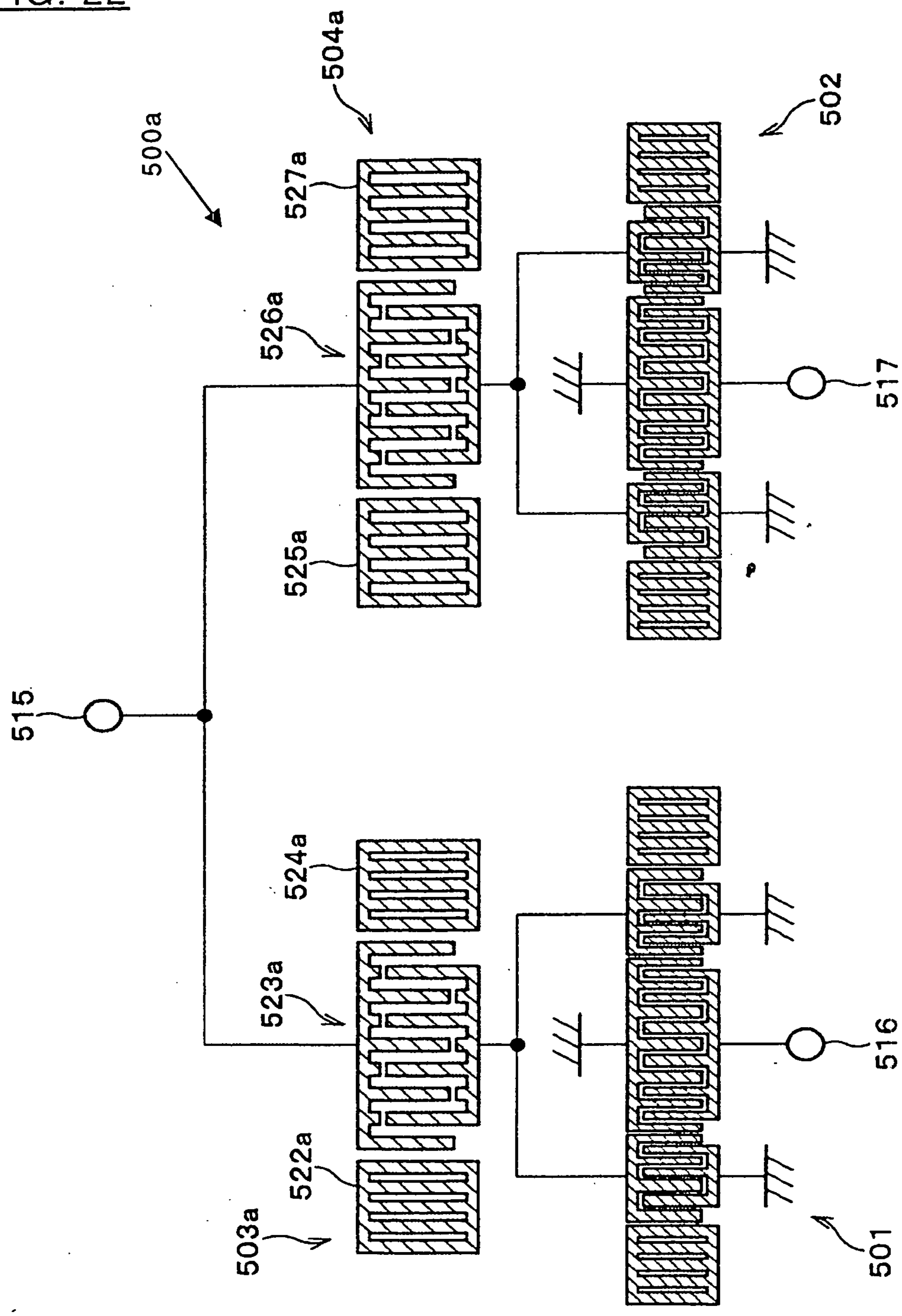

500a
504a
527a
526a
525a
502
517
515
524a
523a
522a
503a
516
501

FIG. 23

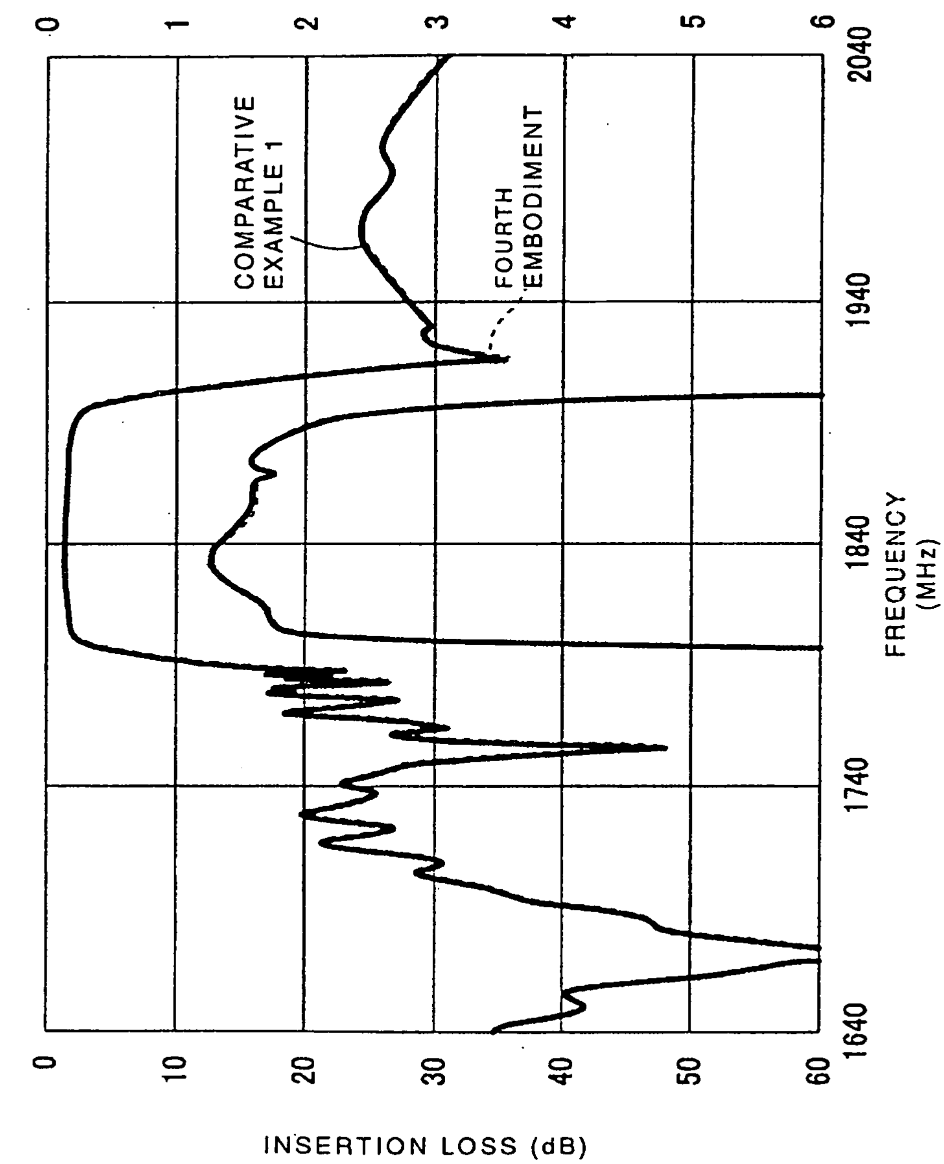

COMPARATIVE EXAMPLE 1
FOURTH EMBODIMENT
0
1
2
3
4
5
6
0
10
20
30
40
50
60
1640
1740
1840
1940
2040
FREQUENCY (MHz)
INSERTION LOSS (dB)

FIG. 24

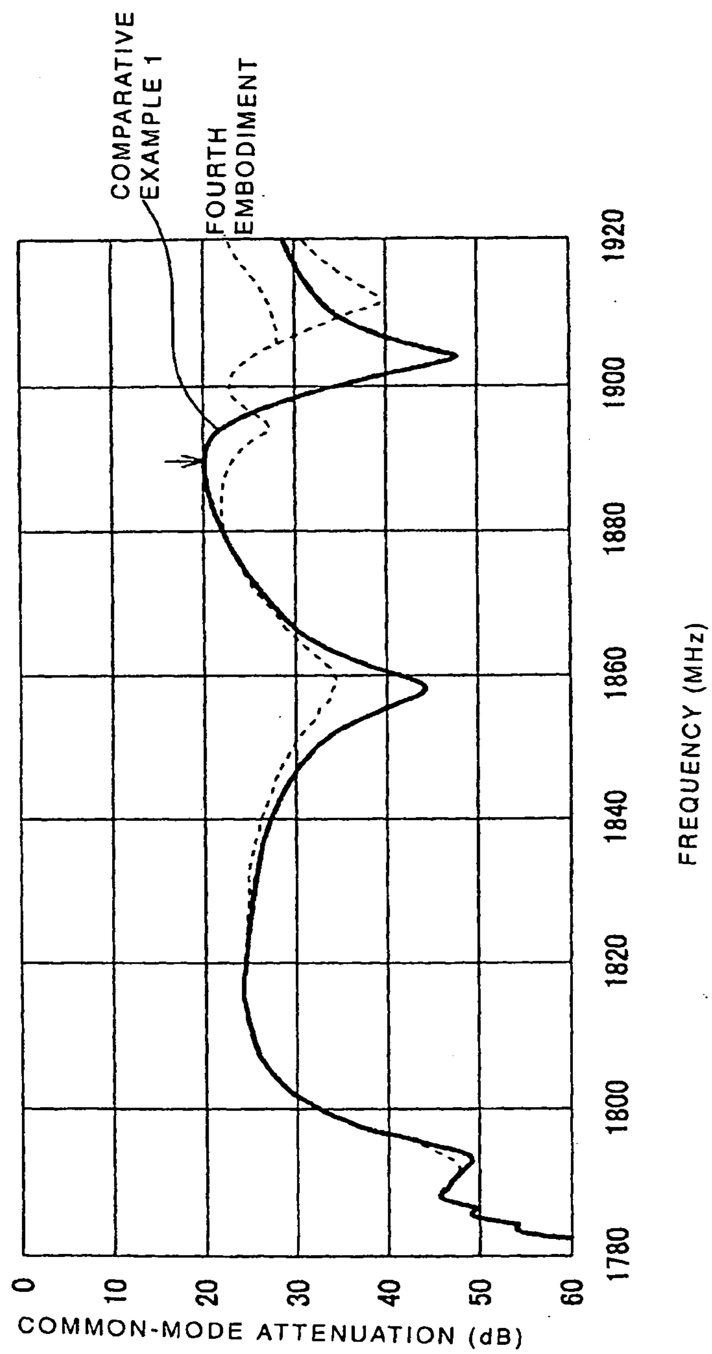

COMPARATIVE EXAMPLE 1
FOURTH EMBODIMENT
0
10
20
30
40
50
60
COMMON-MODE ATTENUATION (dB)
1780
1800
1820
1840
1860
1880
1900
1920
FREQUENCY (MHz)

FIG. 25

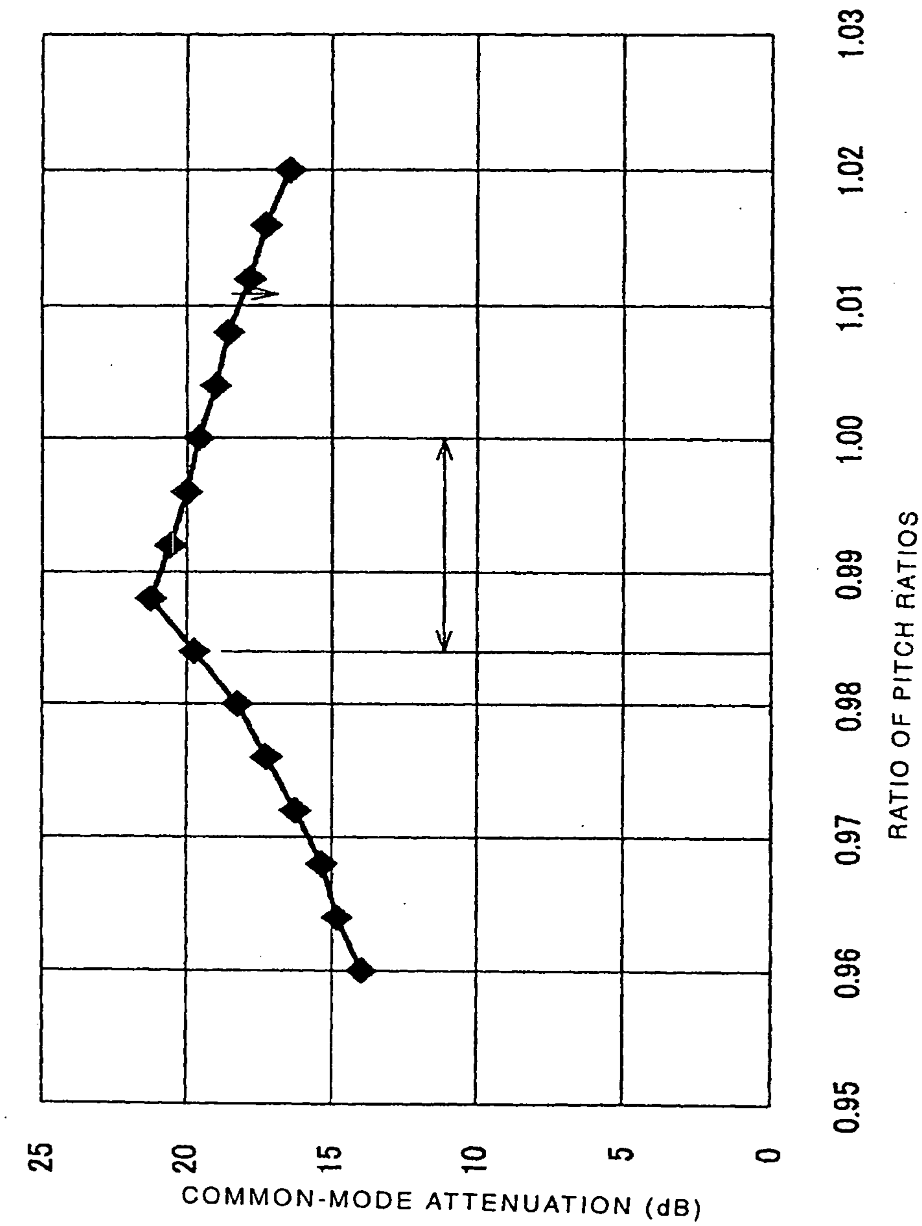

COMMON-MODE ATTENUATION (dB)
25
20
15
10
5
0
RATIO OF PITCH RATIOS
0.95
0.96
0.97
0.98
0.99
1.00
1.01
1.02
1.03

FIG. 26

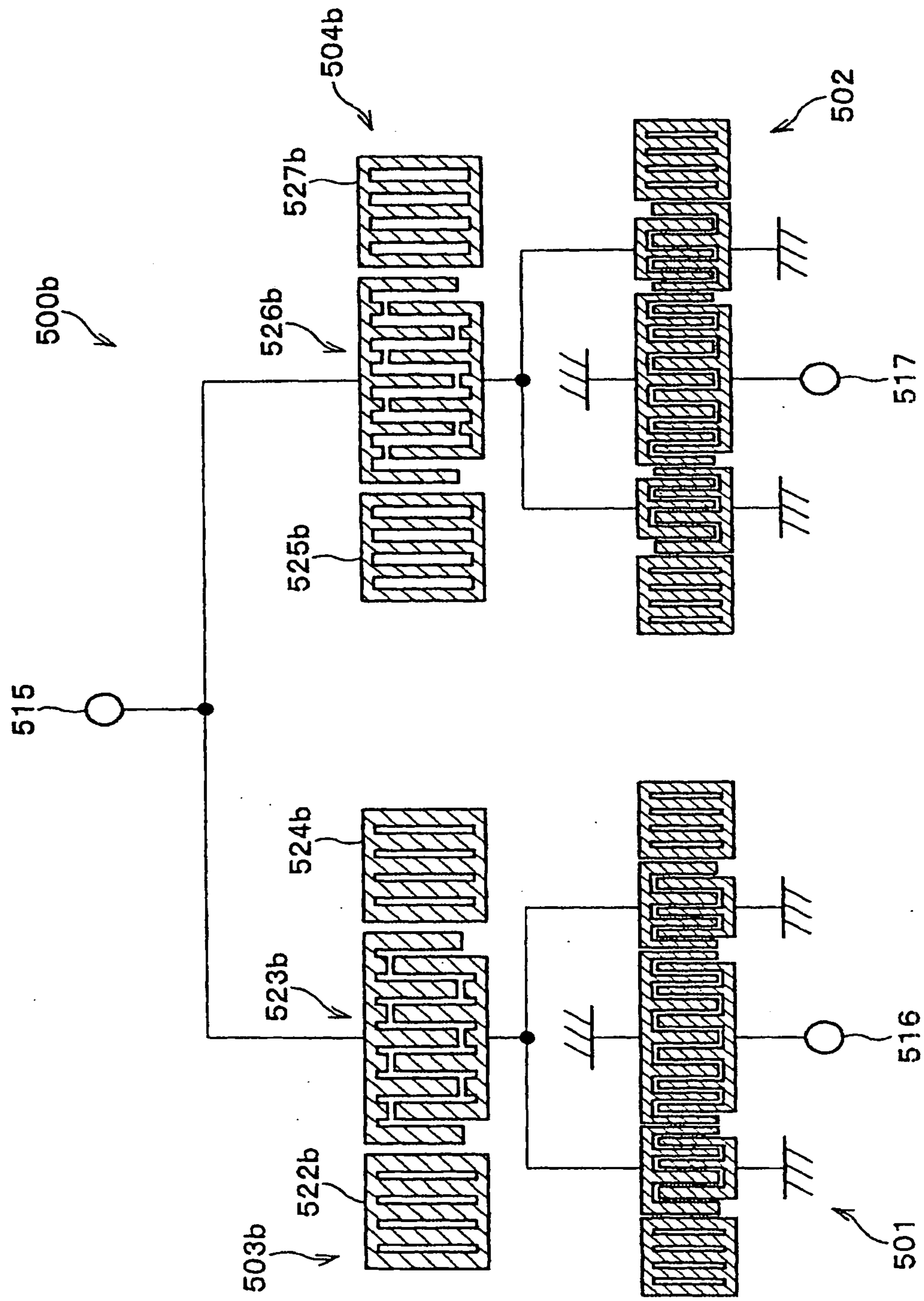

500b
504b
527b
526b
525b
502
517
515
524b
523b
522b
503b
516
501

FIG. 27

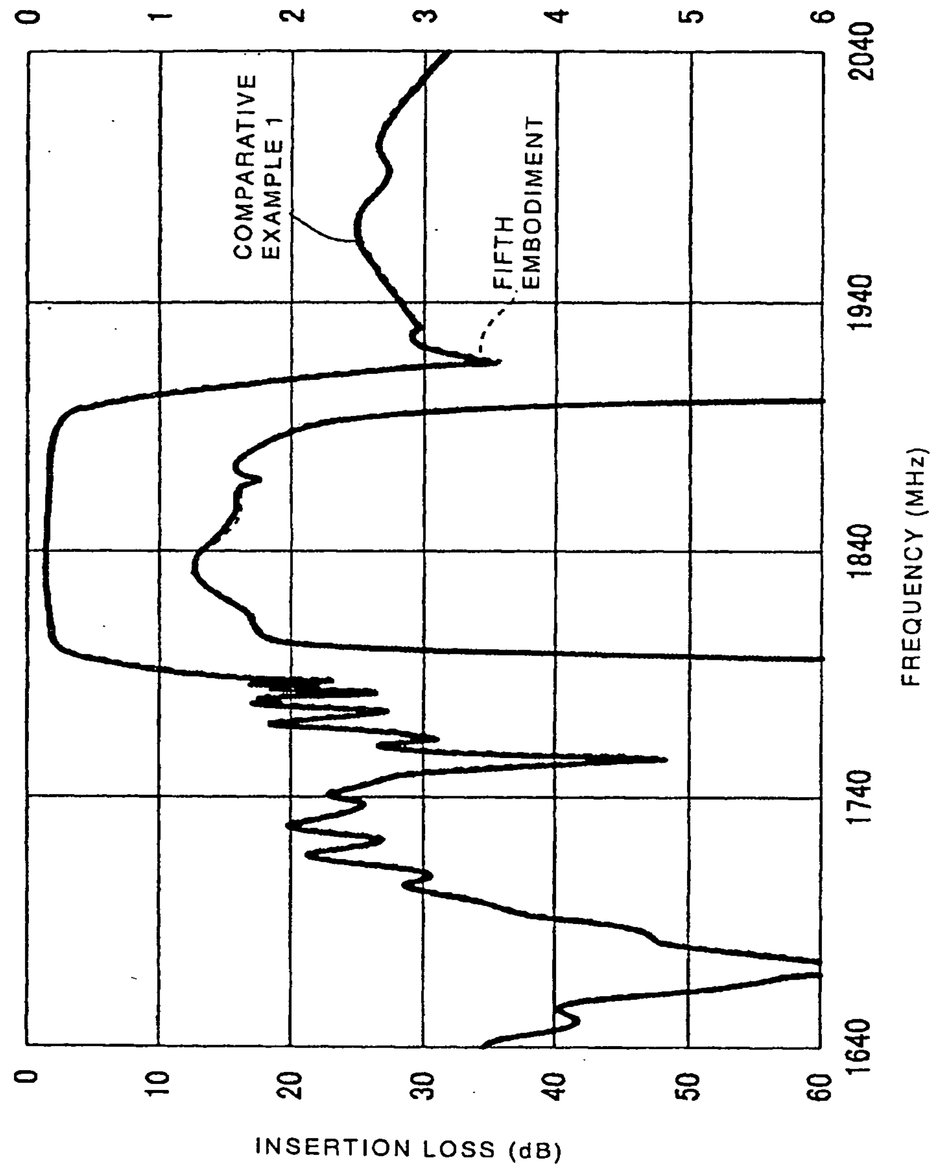

COMPARATIVE EXAMPLE 1
FIFTH EMBODIMENT
FREQUENCY (MHz)
1640
1740
1840
1940
2040
INSERTION LOSS (dB)
0
10
20
30
40
50
60
0
1
2
3
4
5
6

FIG. 28

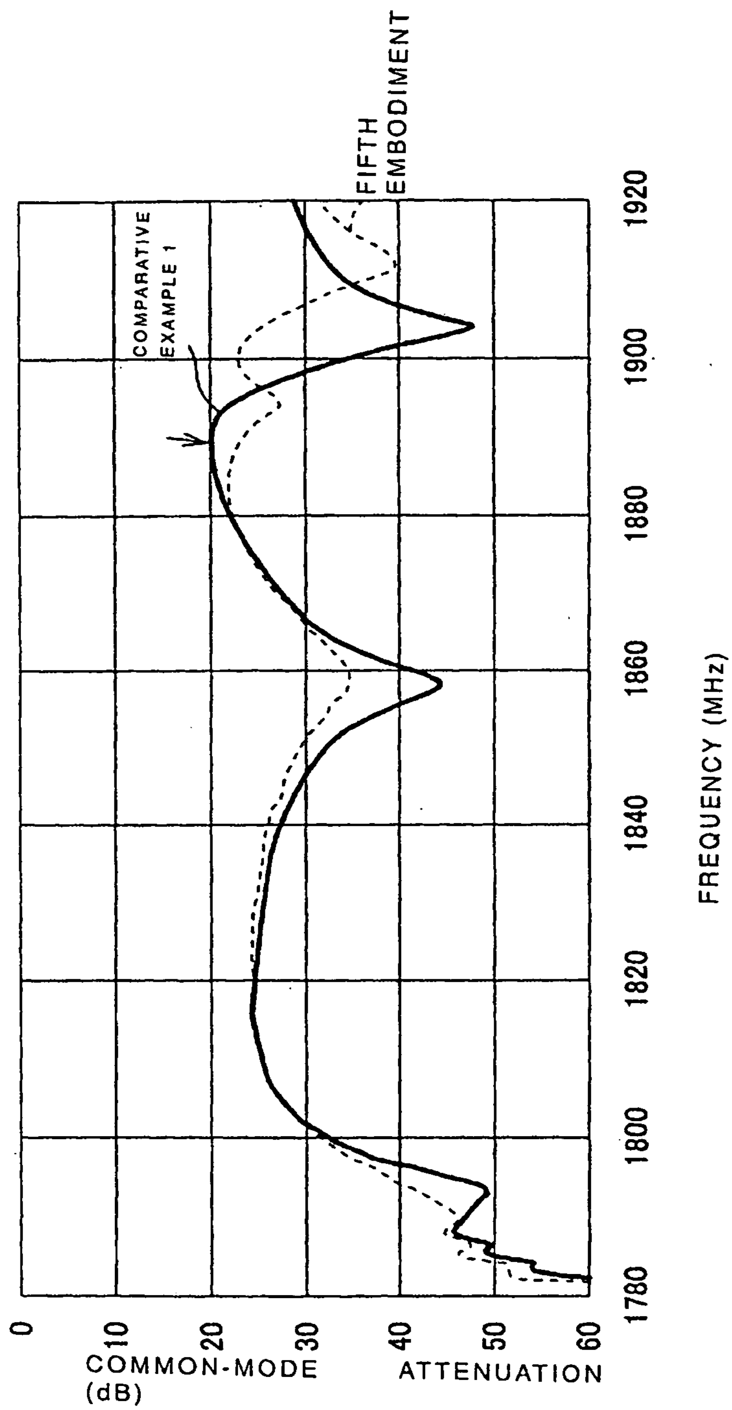
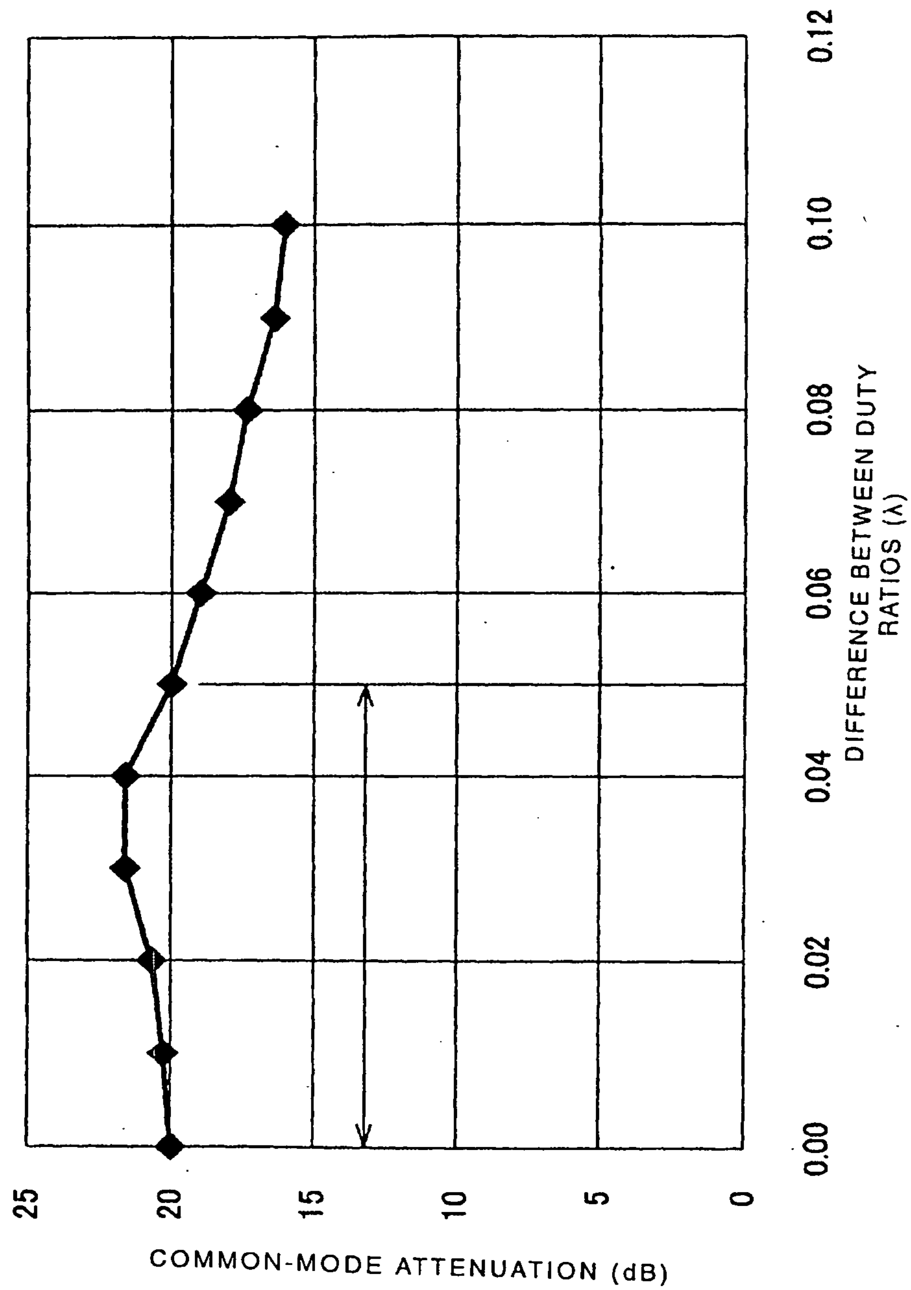

COMPARATIVE EXAMPLE 1
FIFTH EMBODIMENT
1780
1800
1820
1840
1860
1880
1900
1920
FREQUENCY (MHz)
0
10
20
30
40
50
60
COMMON-MODE ATTENUATION (dB)

FIG. 29


25
20
15
10
5
0
COMMON-MODE ATTENUATION (dB)
0.00
0.02
0.04
0.06
0.08
0.10
0.12
DIFFERENCE BETWEEN DUTY RATIOS (λ)